US008792271B2

(12) **United States Patent**
Morise et al.

(10) **Patent No.: US 8,792,271 B2**
(45) **Date of Patent: Jul. 29, 2014**

(54) **MAGNETIC MEMORY DEVICE AND METHOD OF MAGNETIC DOMAIN WALL MOTION**

(75) Inventors: **Hirofumi Morise**, Kanagawa-ken (JP); **Hideaki Fukuzawa**, Kanagawa-ken (JP); **Akira Kikitsu**, Kanagawa-ken (JP); **Yoshiaki Fukuzumi**, Kanagawa-ken (JP)

(73) Assignee: **Kabushiki Kaisha Toshiba**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 349 days.

(21) Appl. No.: **13/282,605**

(22) Filed: **Oct. 27, 2011**

(65) **Prior Publication Data**

US 2012/0250406 A1 Oct. 4, 2012

(30) **Foreign Application Priority Data**

Mar. 30, 2011 (JP) 2011-076416

(51) **Int. Cl.**
G11C 11/15 (2006.01)

(52) **U.S. Cl.**
USPC **365/173**; 365/148; 365/157; 365/158; 365/171; 977/933; 977/935

(58) **Field of Classification Search**
USPC 365/48, 55, 62, 66, 74, 78, 80–93, 100, 365/130, 131, 148, 158, 157, 171–173, 209, 365/213, 225.5, 230.07, 232, 243.5; 257/295, 421, 422, 427, E21.665, 257/E27.006; 438/3; 977/933–935
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,883,760	A *	3/1999	Yamada et al.	.... 360/76
6,236,538	B1 *	5/2001	Yamada et al.	.... 360/123.6
6,834,005	B1	12/2004	Parkin	
8,138,758	B2 *	3/2012	Wunderlich et al.	.... 324/252
2008/0165576	A1	7/2008	Deligianni et al.	
2009/0016098	A1 *	1/2009	Wunderlich et al.	.... 365/158
2011/0170339	A1 *	7/2011	Wunderlich et al.	.... 365/158

FOREIGN PATENT DOCUMENTS

JP	2007-324269	12/2007

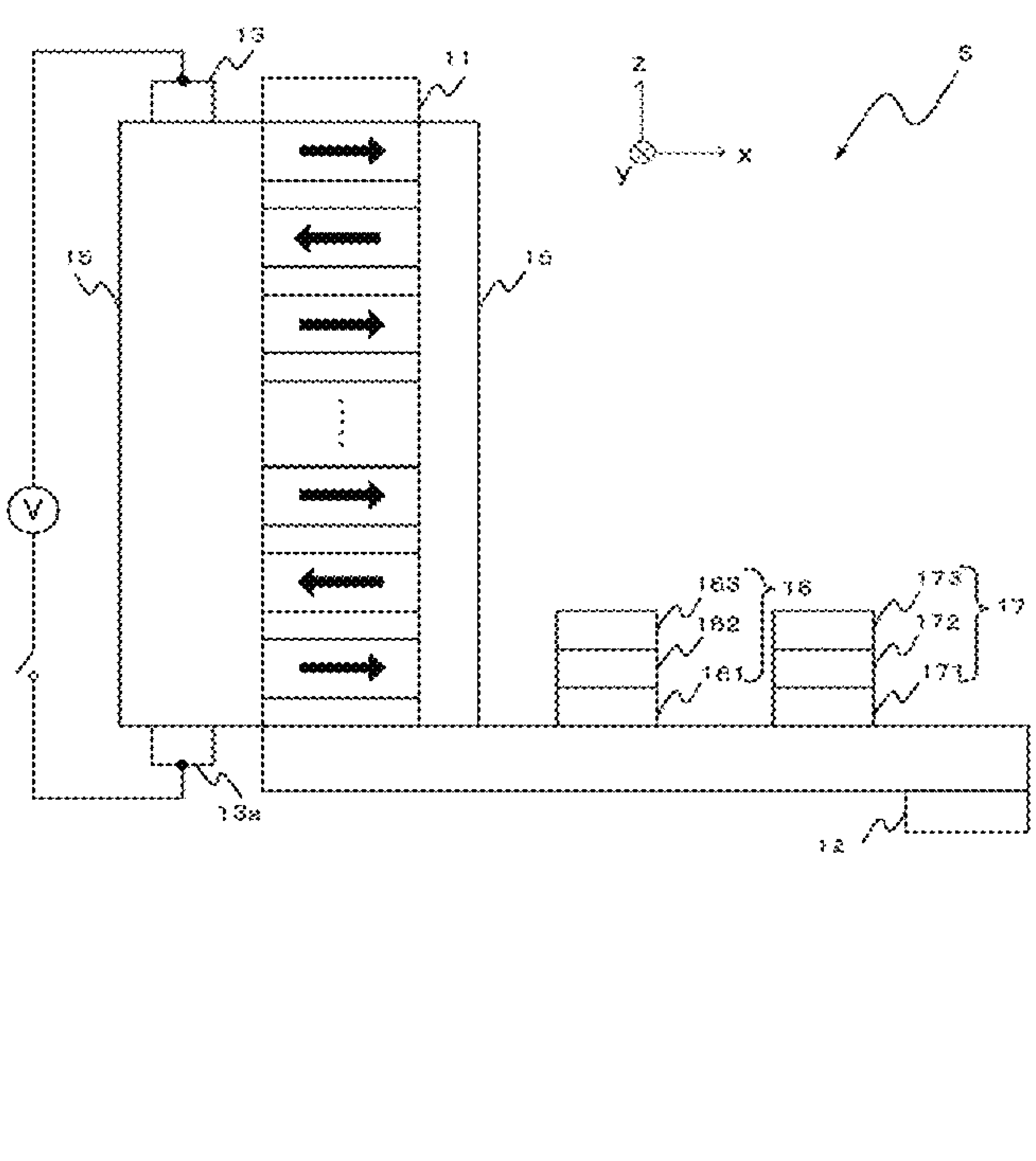
* cited by examiner

Primary Examiner — Harry W Byrne
(74) *Attorney, Agent, or Firm* — Amin, Turocy & Watson, LLP

(57) **ABSTRACT**

A magnetic memory device comprises a first electrode, a second electrode, a laminated structure comprising plural first magnetic layers being provided between the first electrode and the second electrode, a second magnetic layer comprising different composition elements from that of the first magnetic layer and being provided between plural first magnetic layers, a piezoelectric body provided on a opposite side to a side where the first electrode is provided in the laminated structure, and a third electrode applying voltage to the piezoelectric body and provided on a different position from a position where the first electrode is provided in the piezoelectric body.

11 Claims, 29 Drawing Sheets



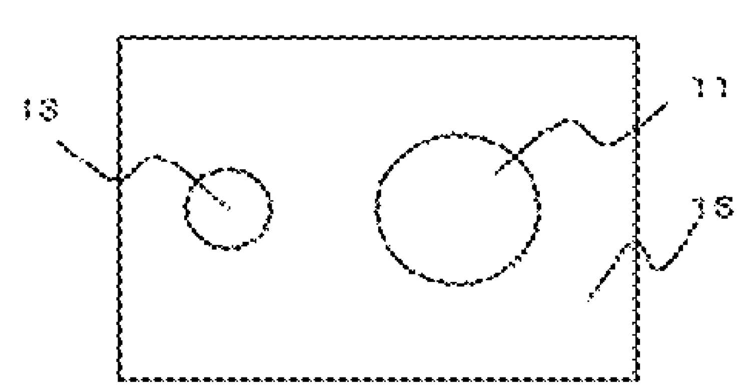


FIG.1

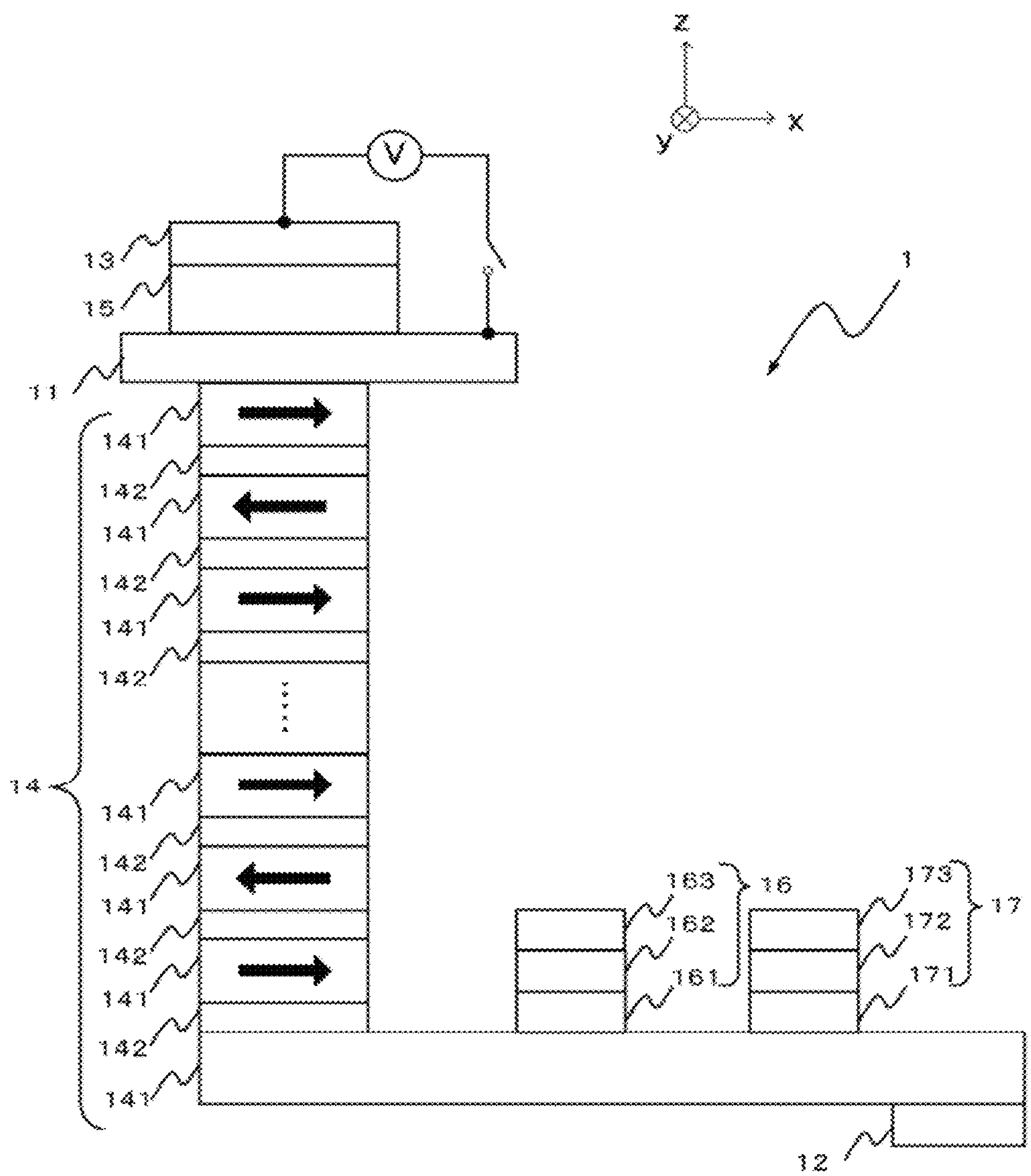
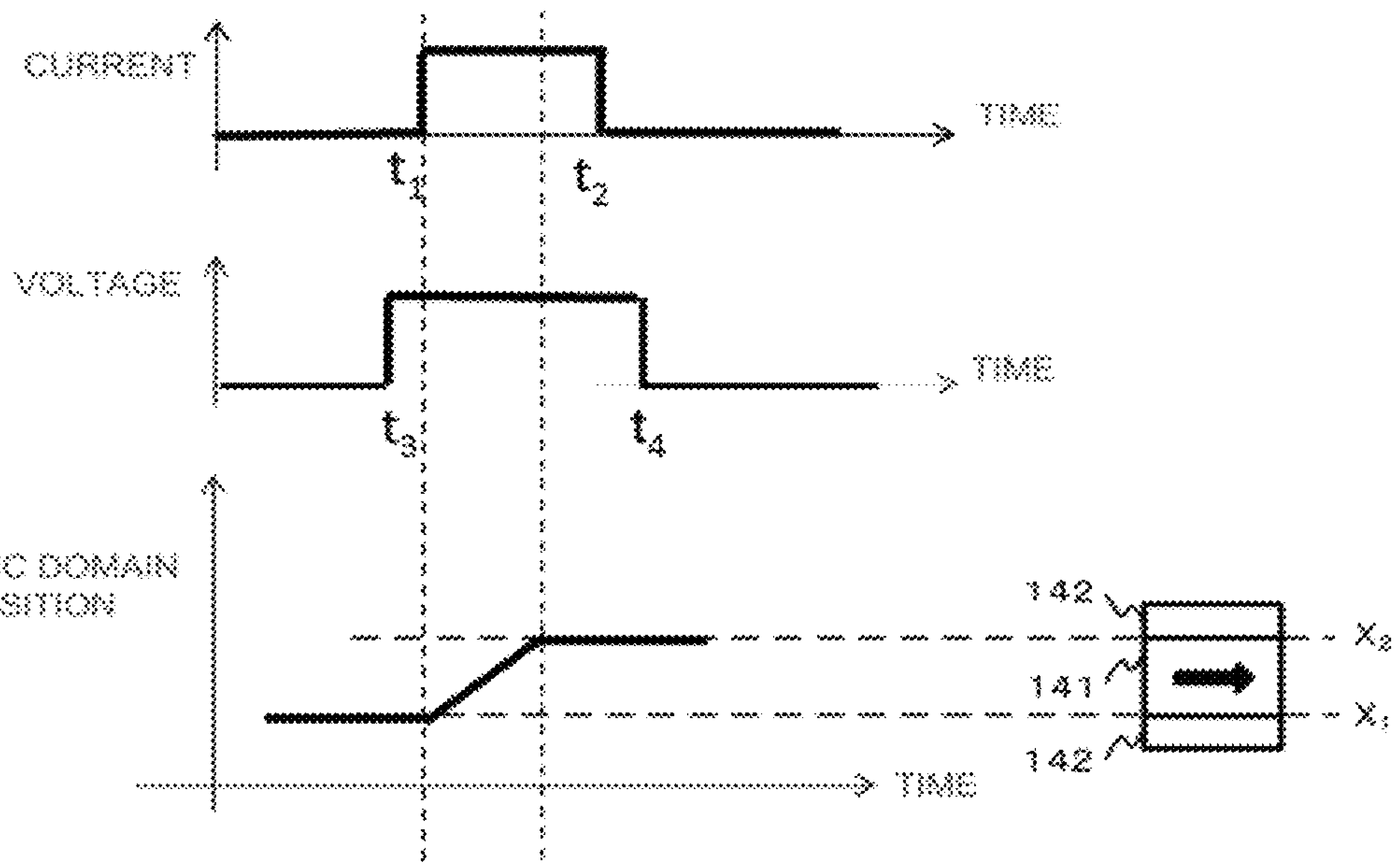

z
x
y
V
1
13
15
11
14
141
142
141
142
141
142
141
142
141
142
141
142
141
163
162
161
16
173
172
171
17
12

FIG.2A

FIG.2B

FIG.2C



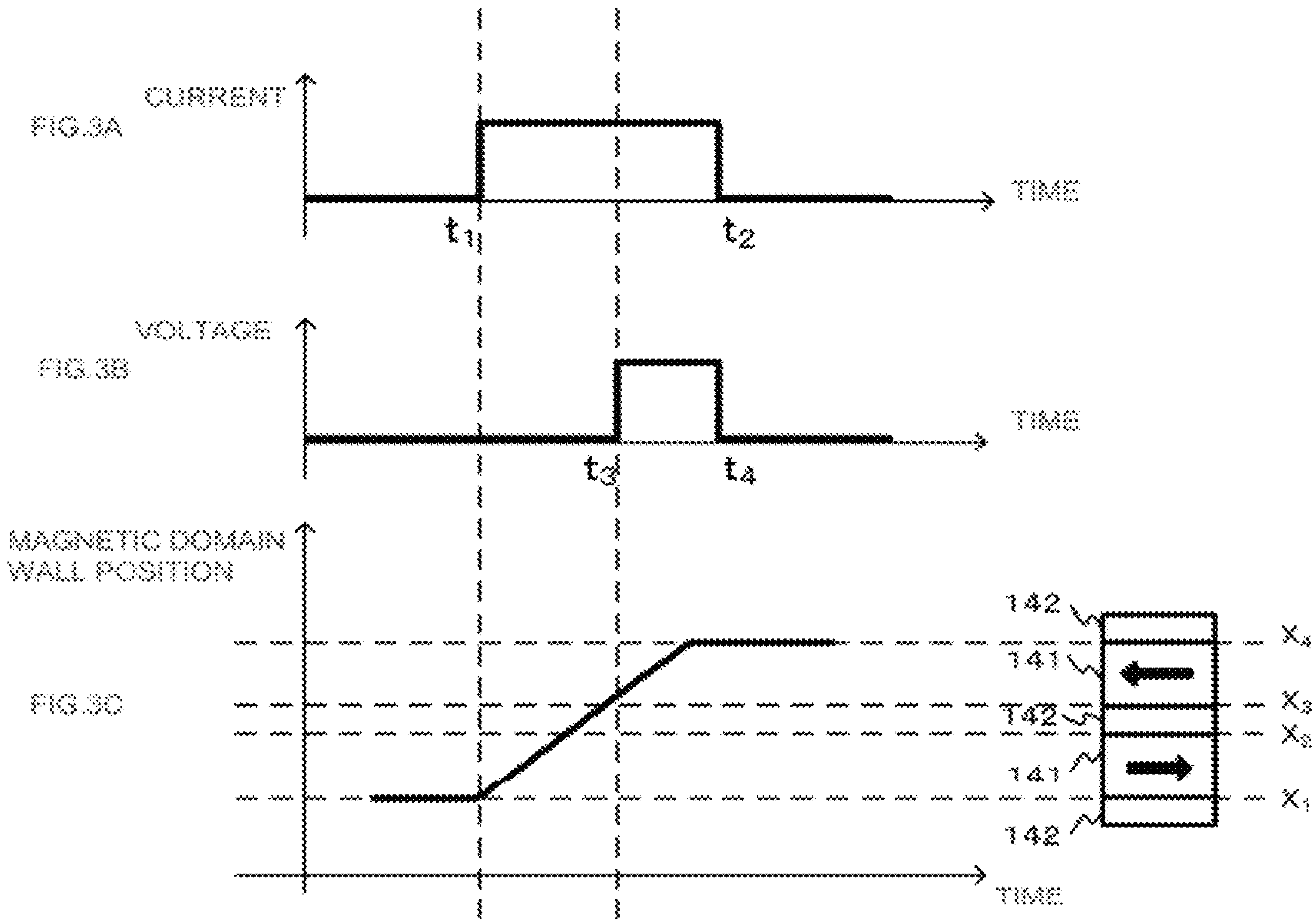


FIG.3A
CURRENT
TIME
t1
t2
FIG.3B
VOLTAGE
TIME
t3
t4
MAGNETIC DOMAIN
WALL POSITION
FIG.3C
142
141
142
141
142
X4
X3
X2
X1
TIME

FIG.4A

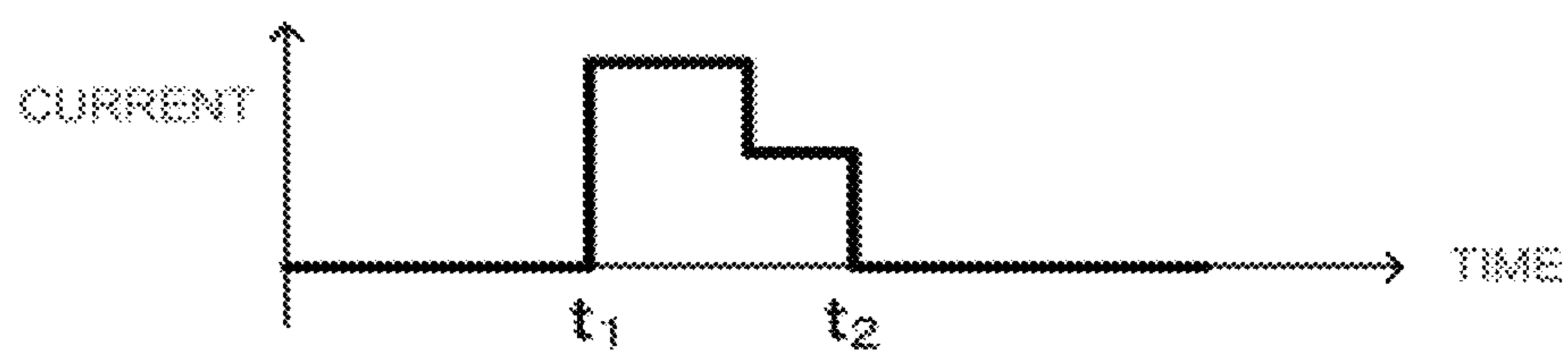


FIG.4B

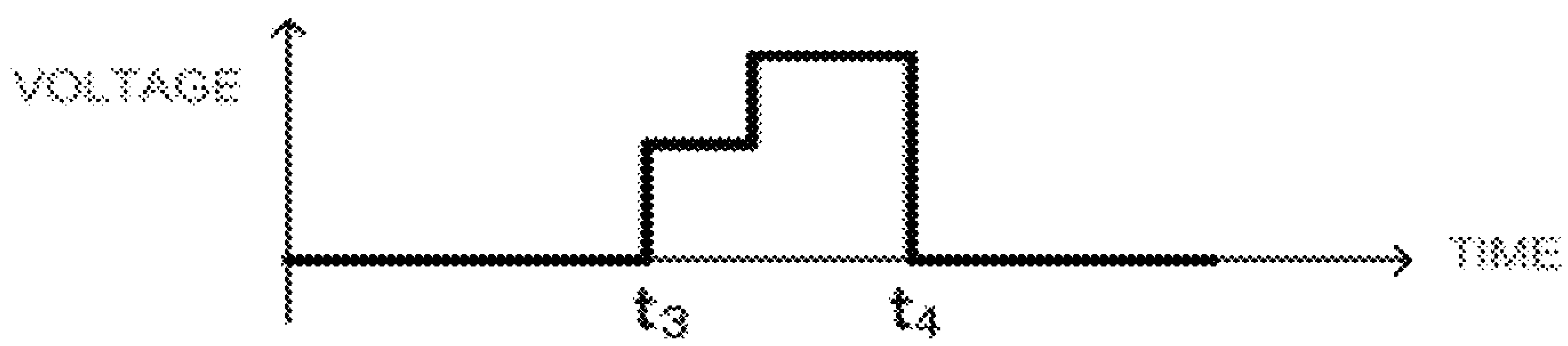


FIG.5

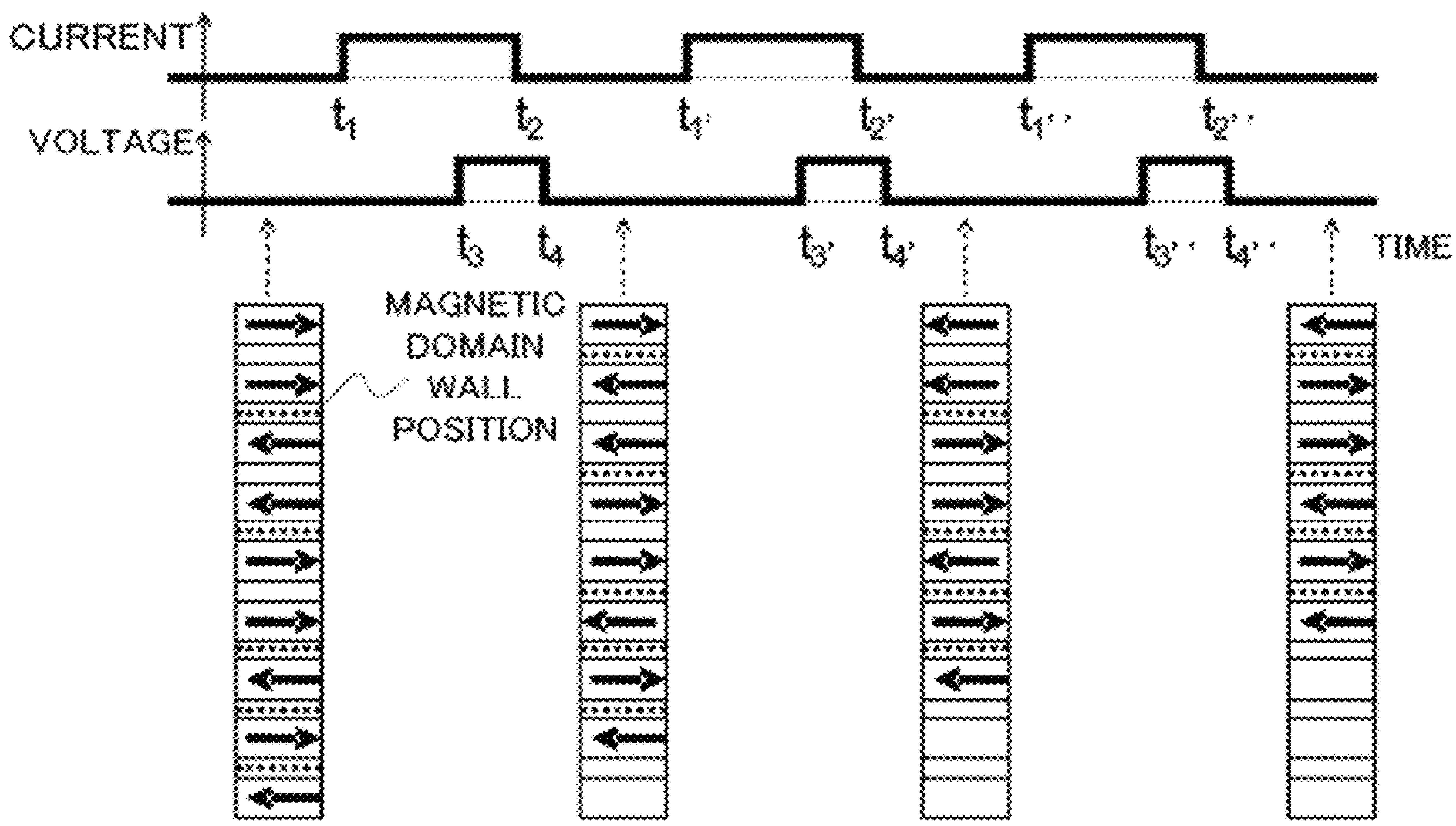

CURRENT
VOLTAGE
t_1
t_2
$t_{1'}$
$t_{2'}$
$t_{1''}$
$t_{2''}$
t_3
t_4
$t_{3'}$
$t_{4'}$
$t_{3''}$
$t_{4''}$
TIME
MAGNETIC DOMAIN WALL POSITION

FIG.6

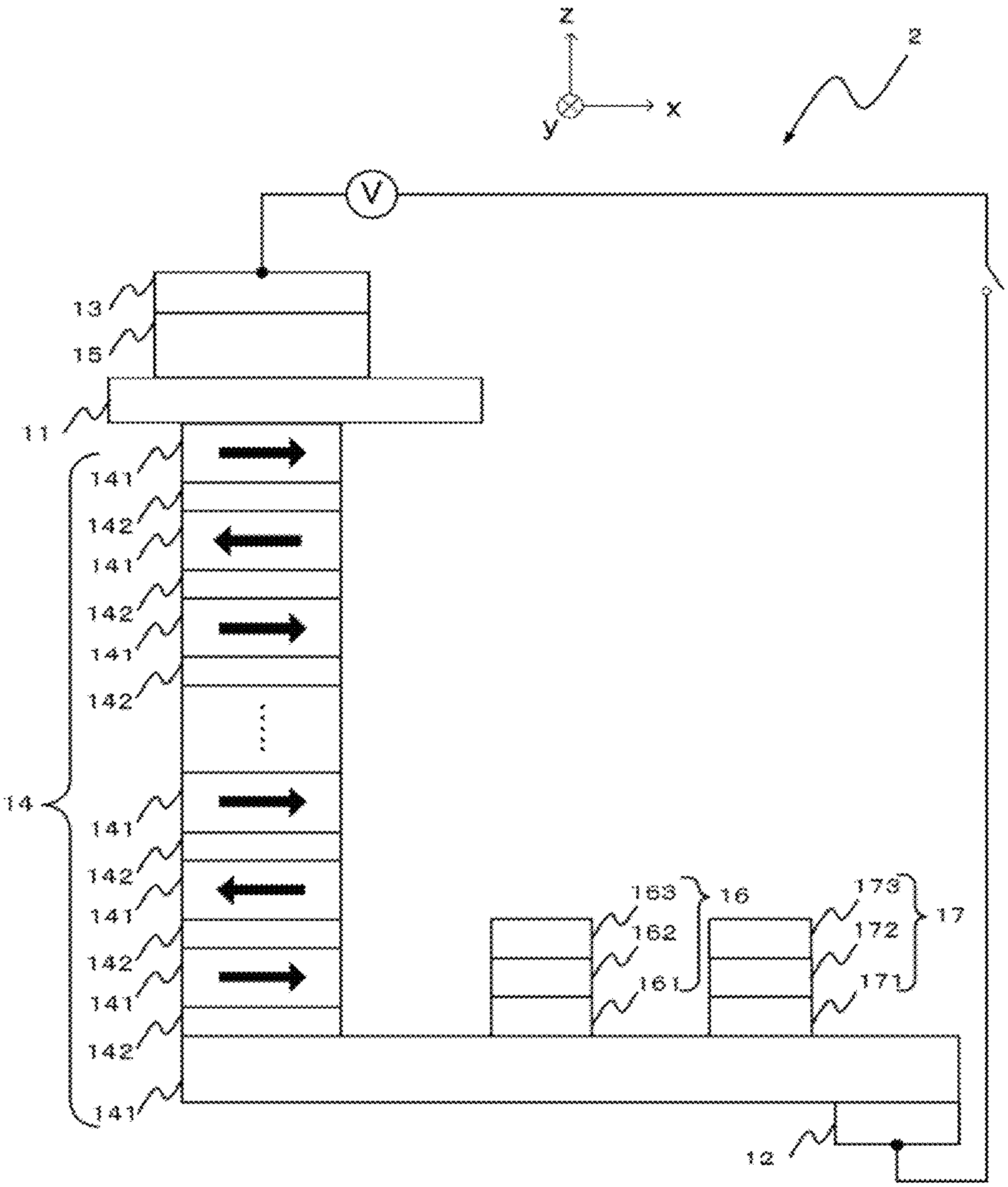

z
x
y
2
V
13
15
11
14
141
142
141
142
141
142
141
142
141
142
141
142
141
163
162
161
16
173
172
171
17
12

FIG.7

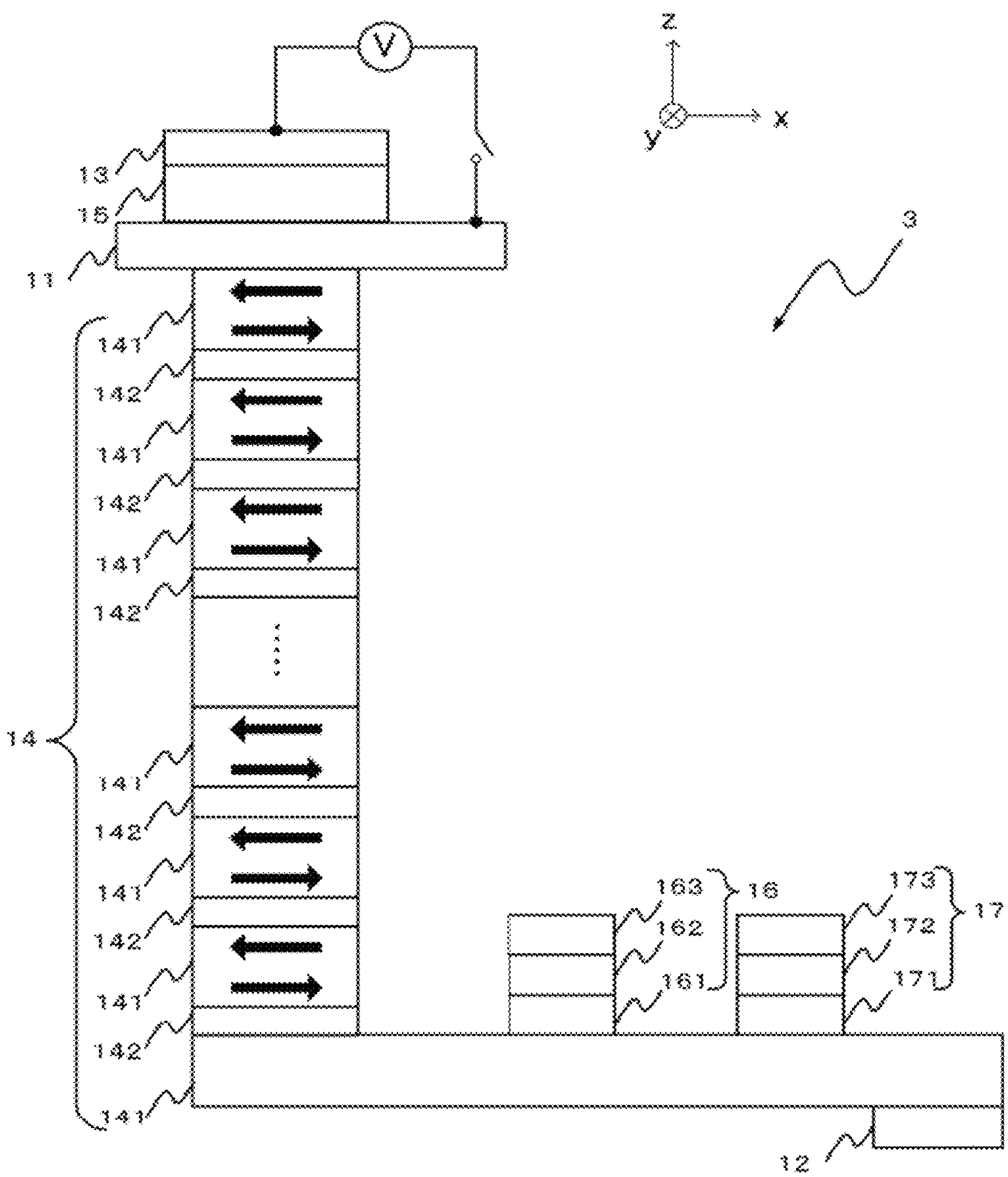


FIG.8

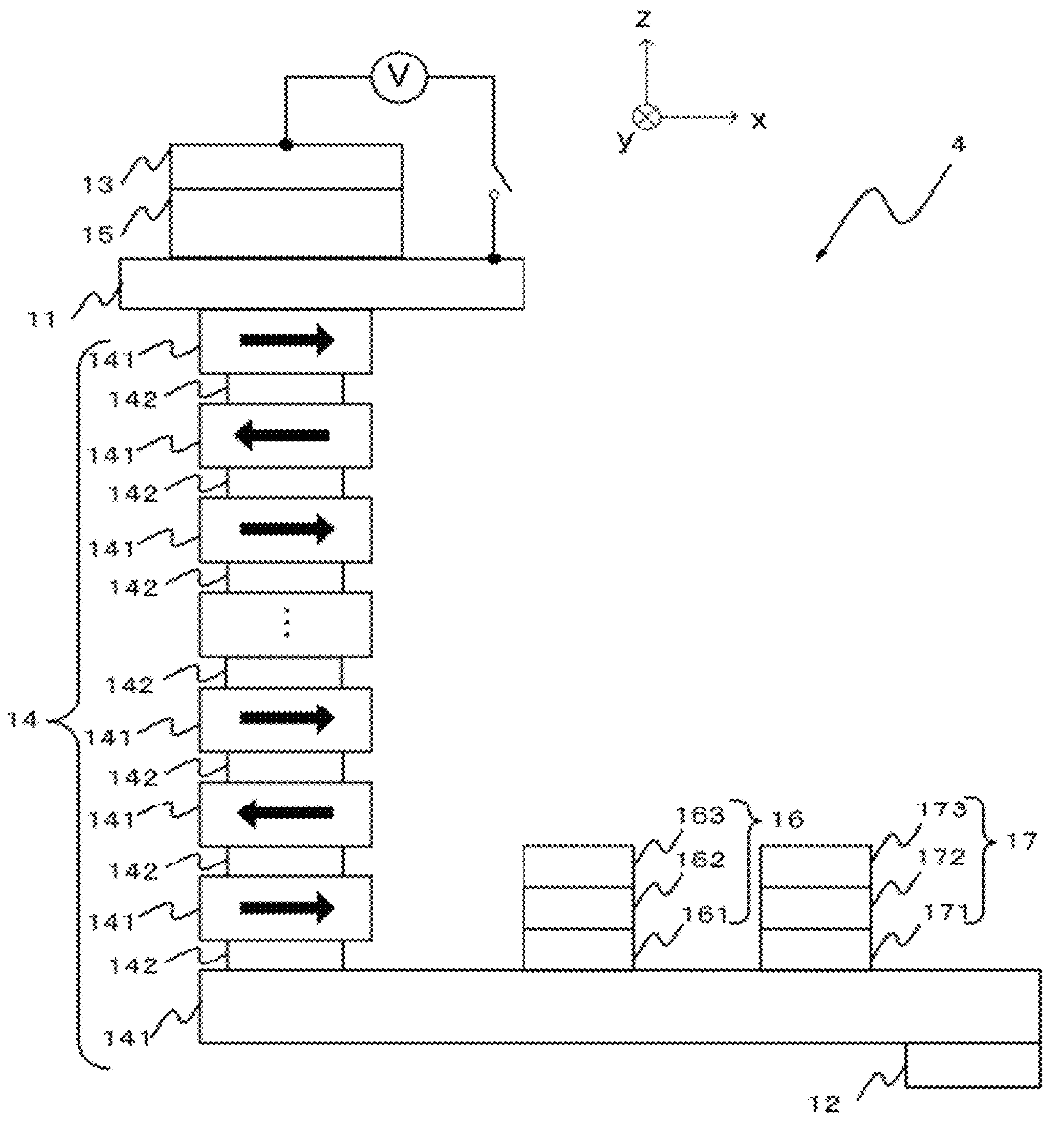


FIG.9A

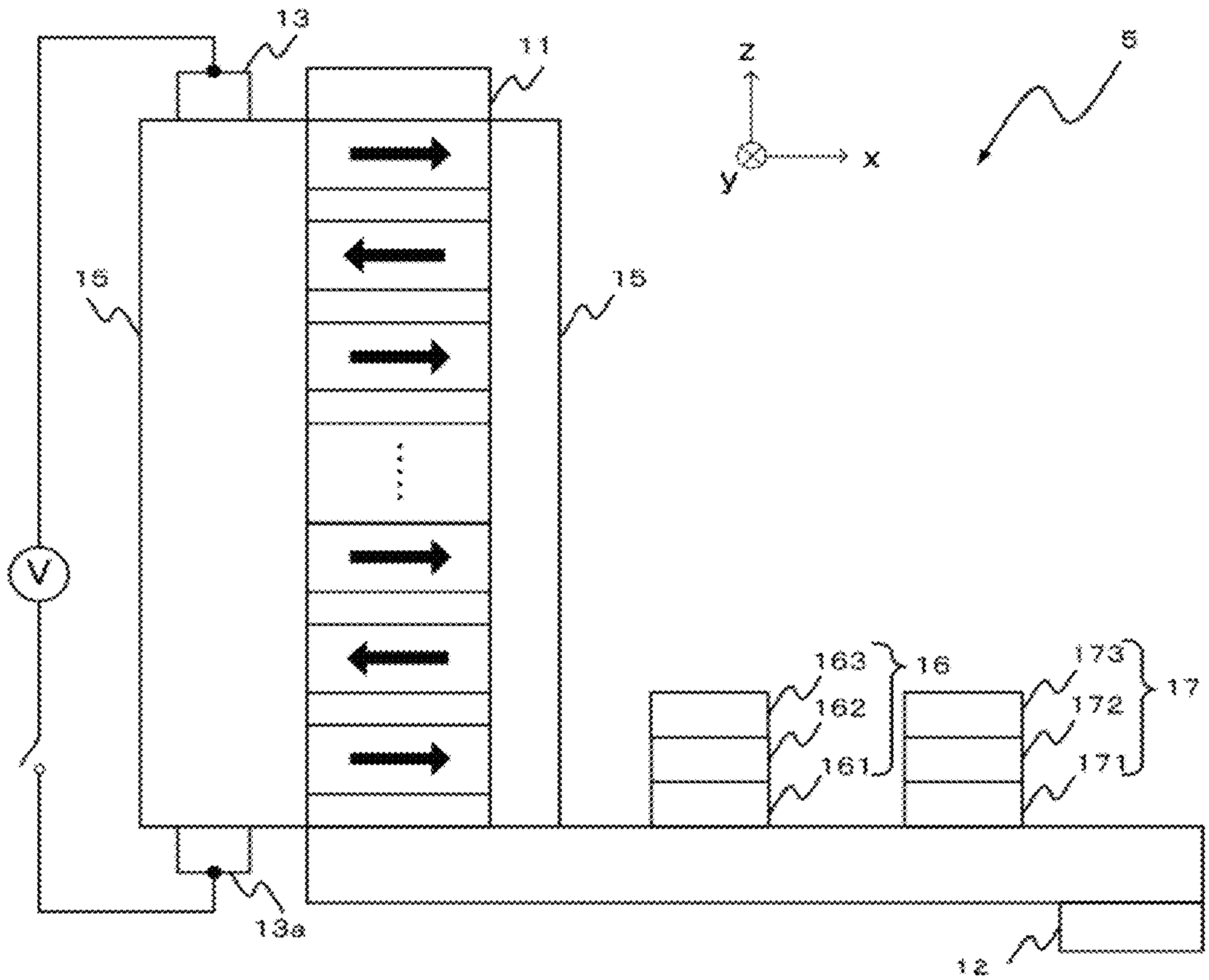


FIG.9B

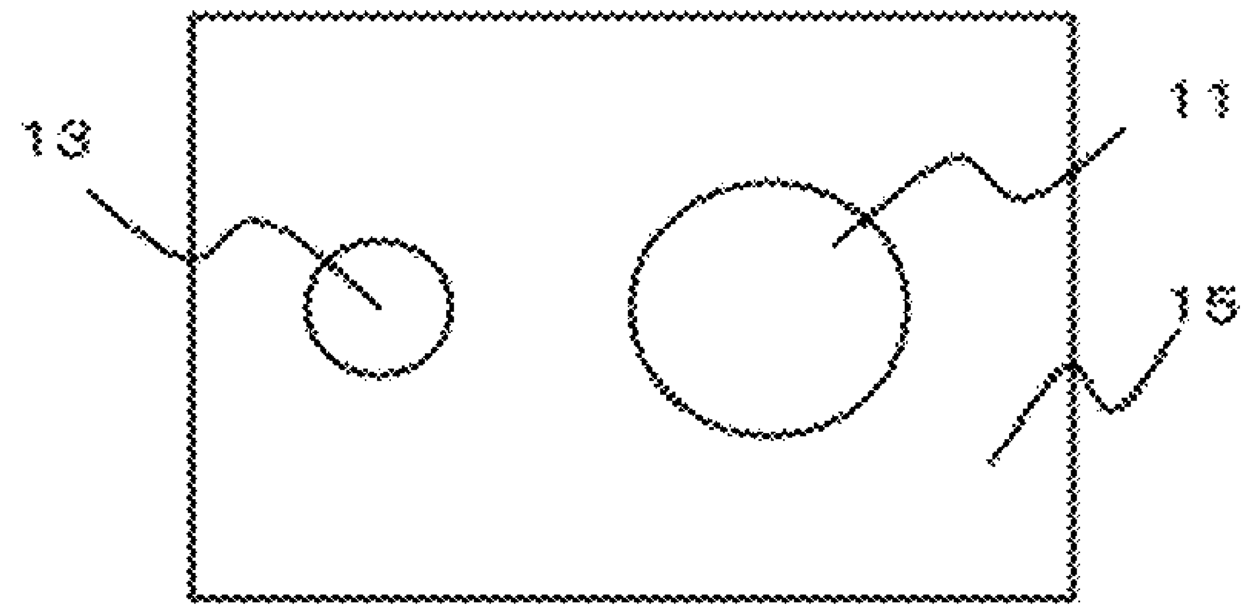


FIG.10A

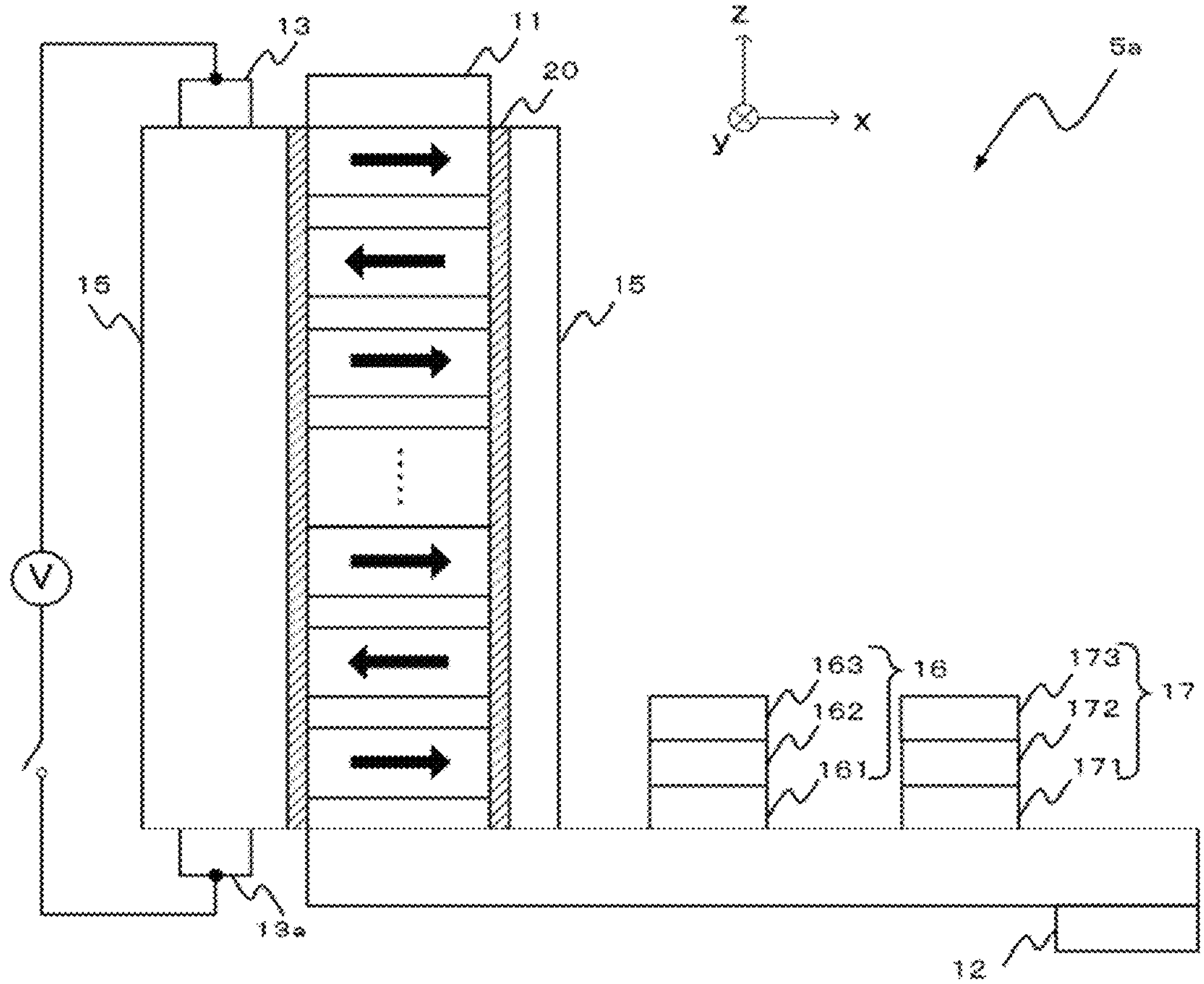


FIG.10B

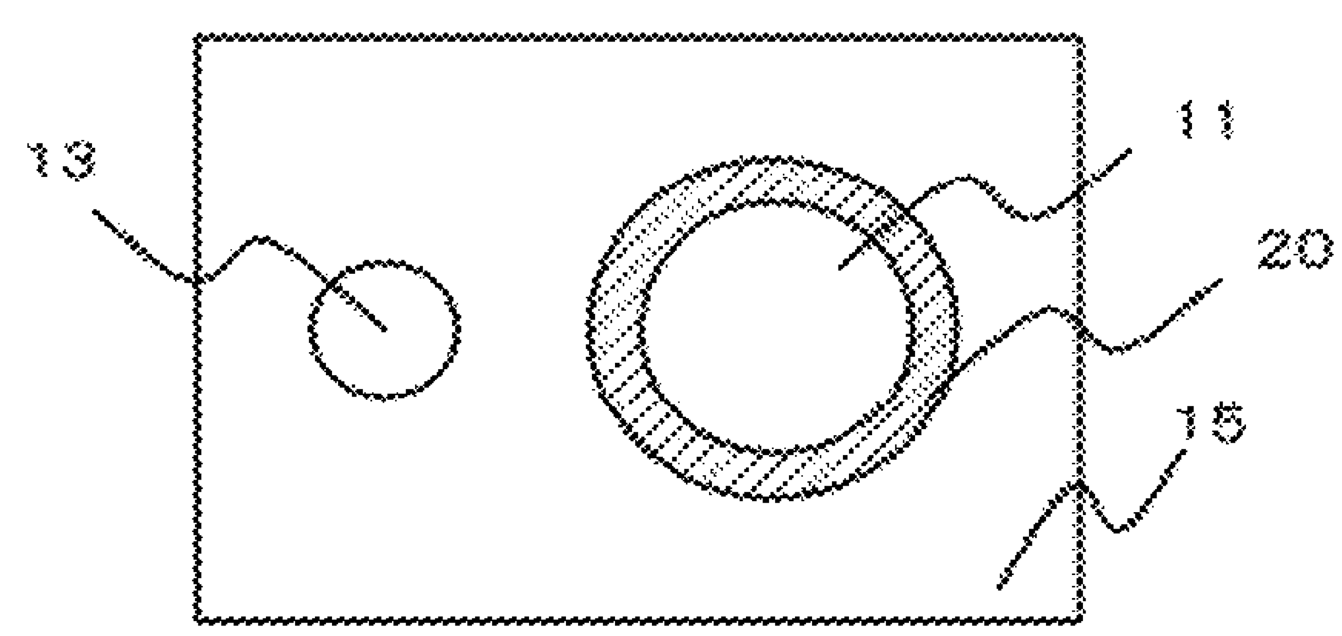


FIG. 11

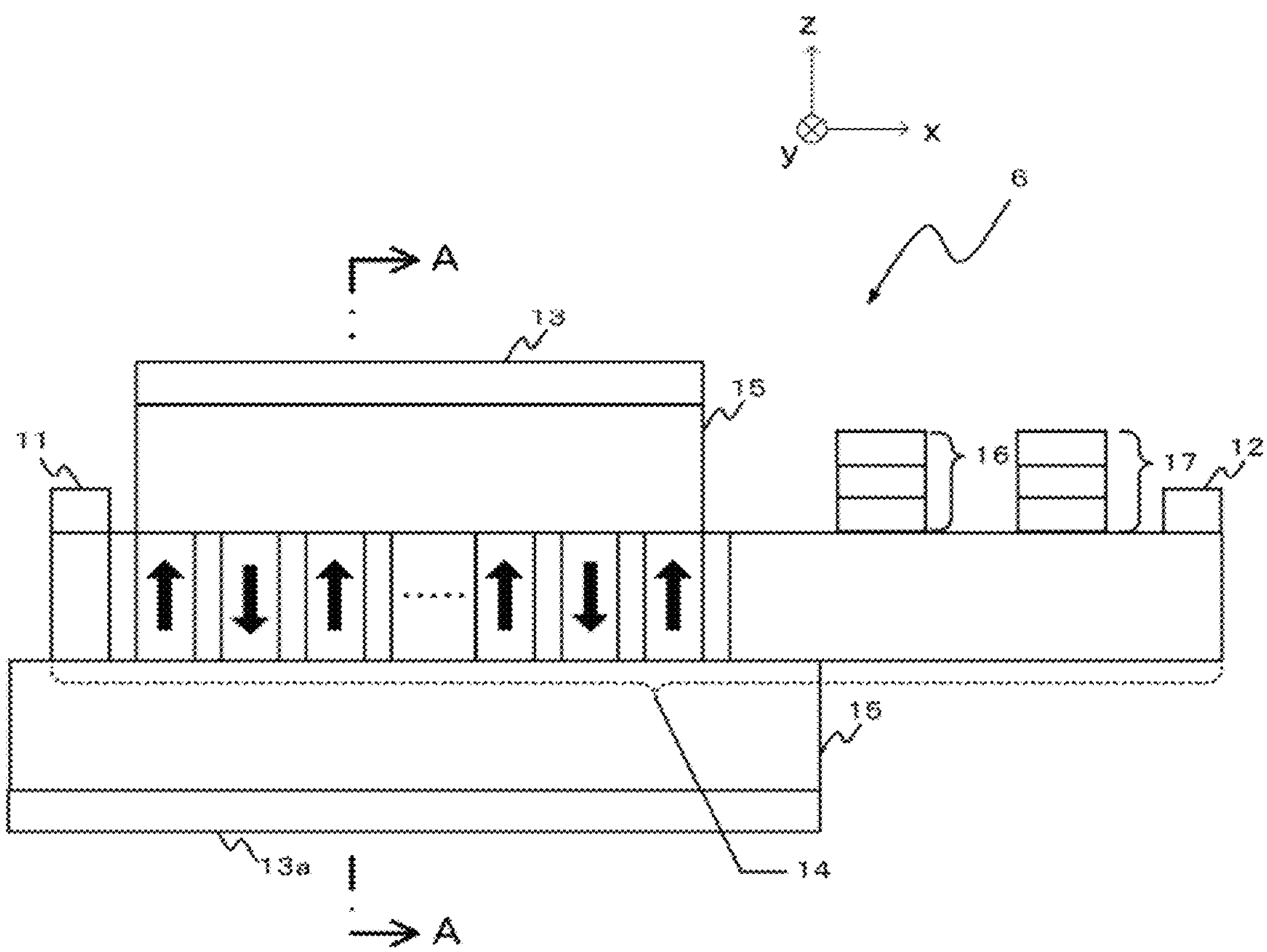


FIG.12

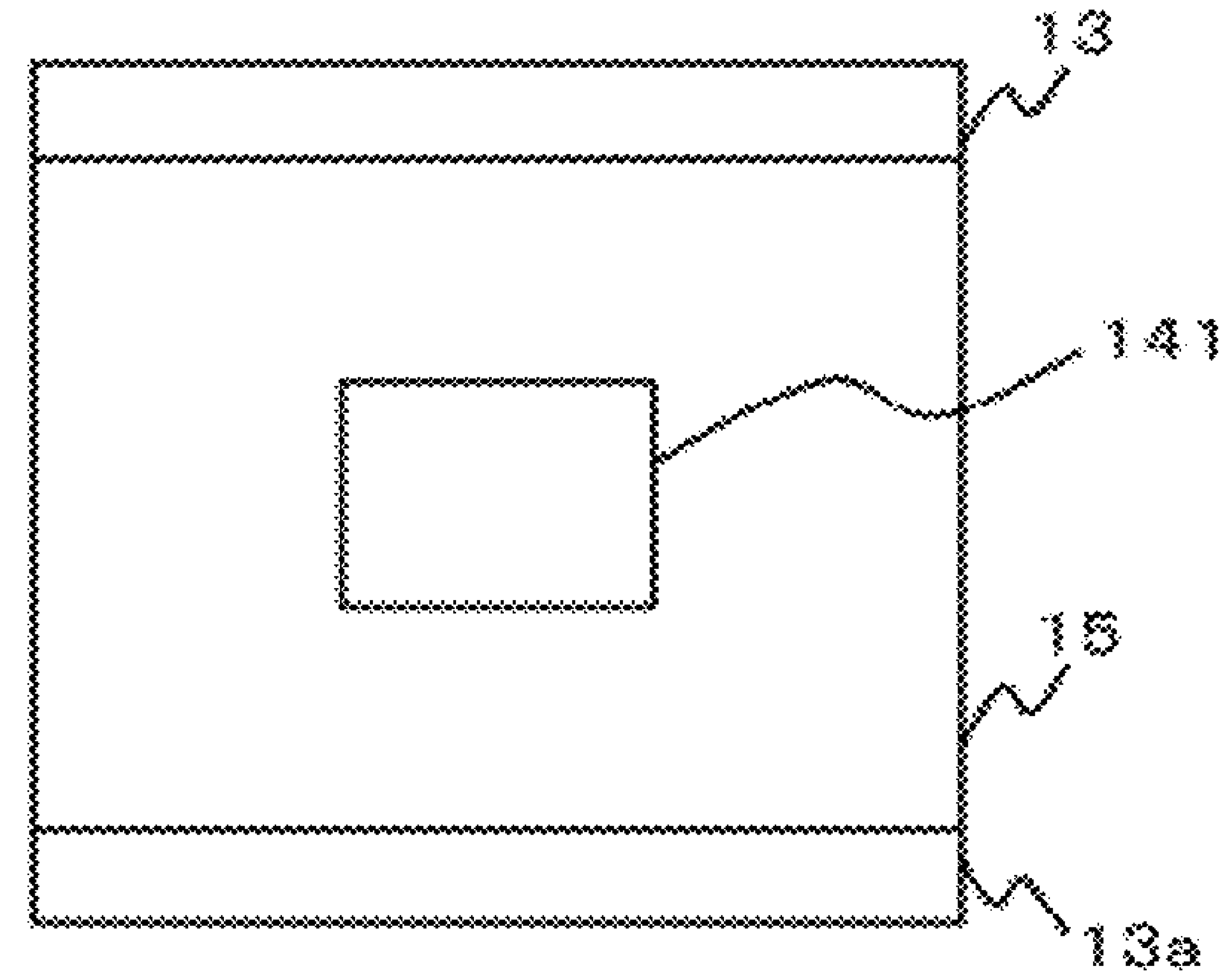


FIG.13

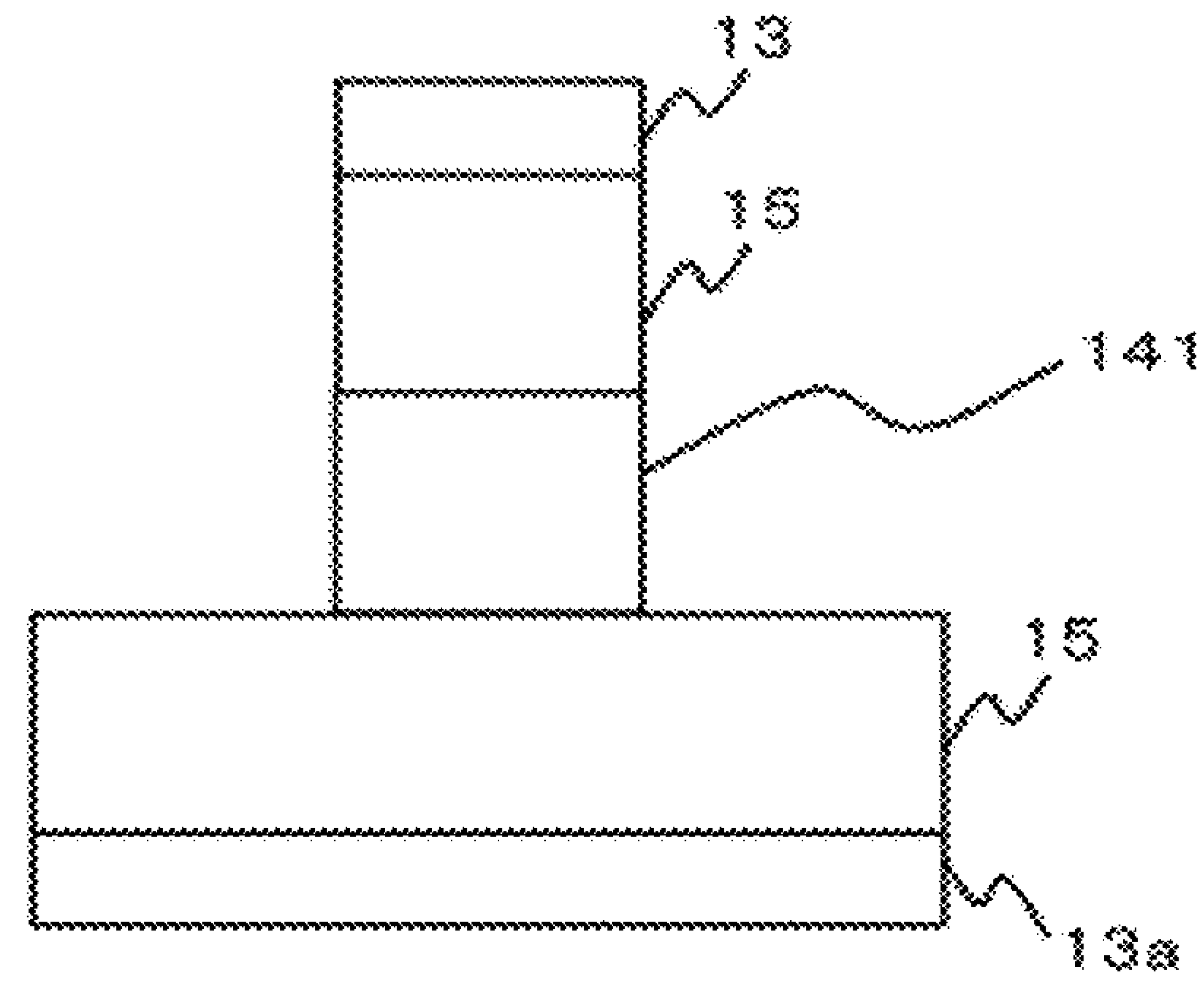


FIG.14

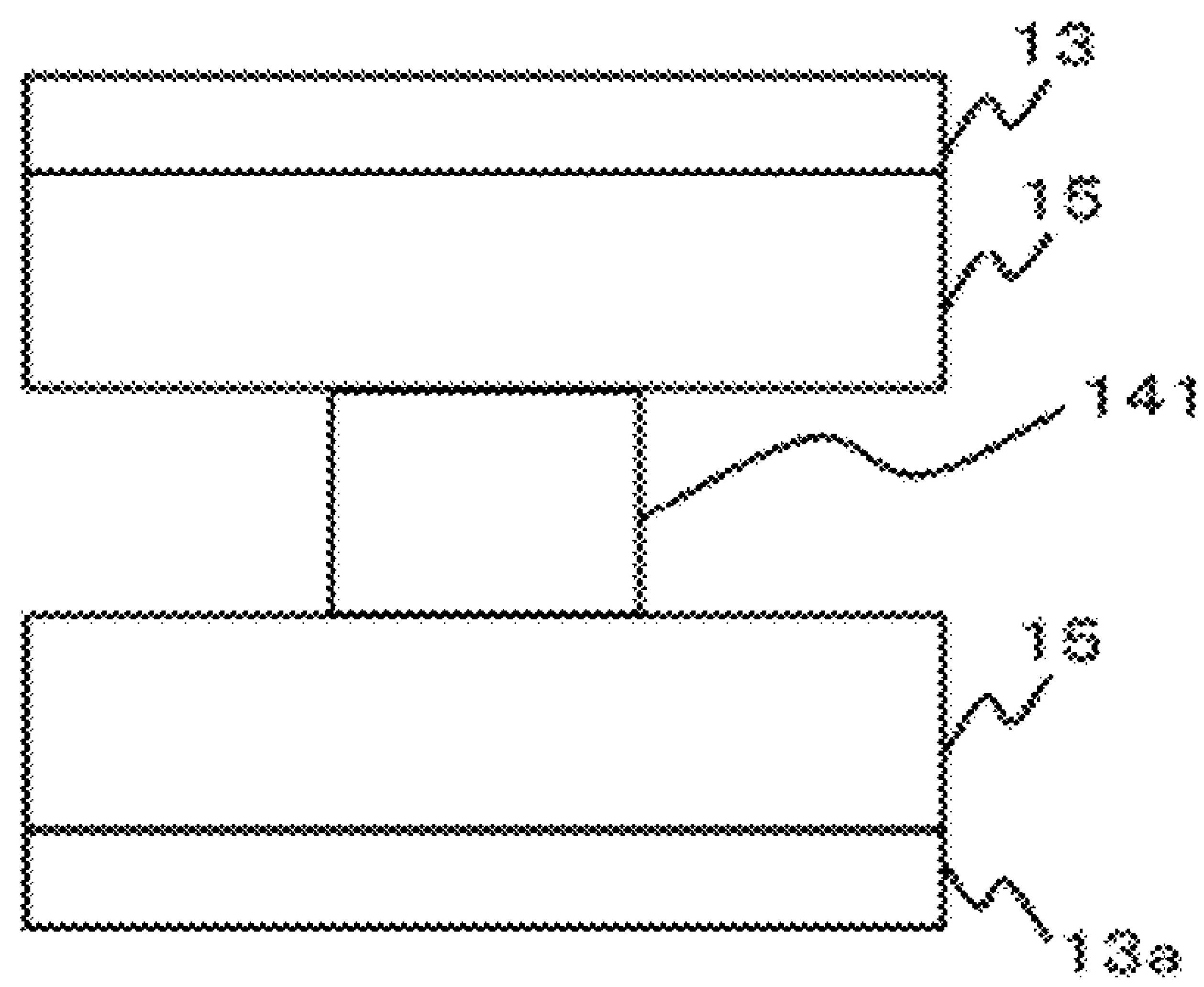


FIG.15A

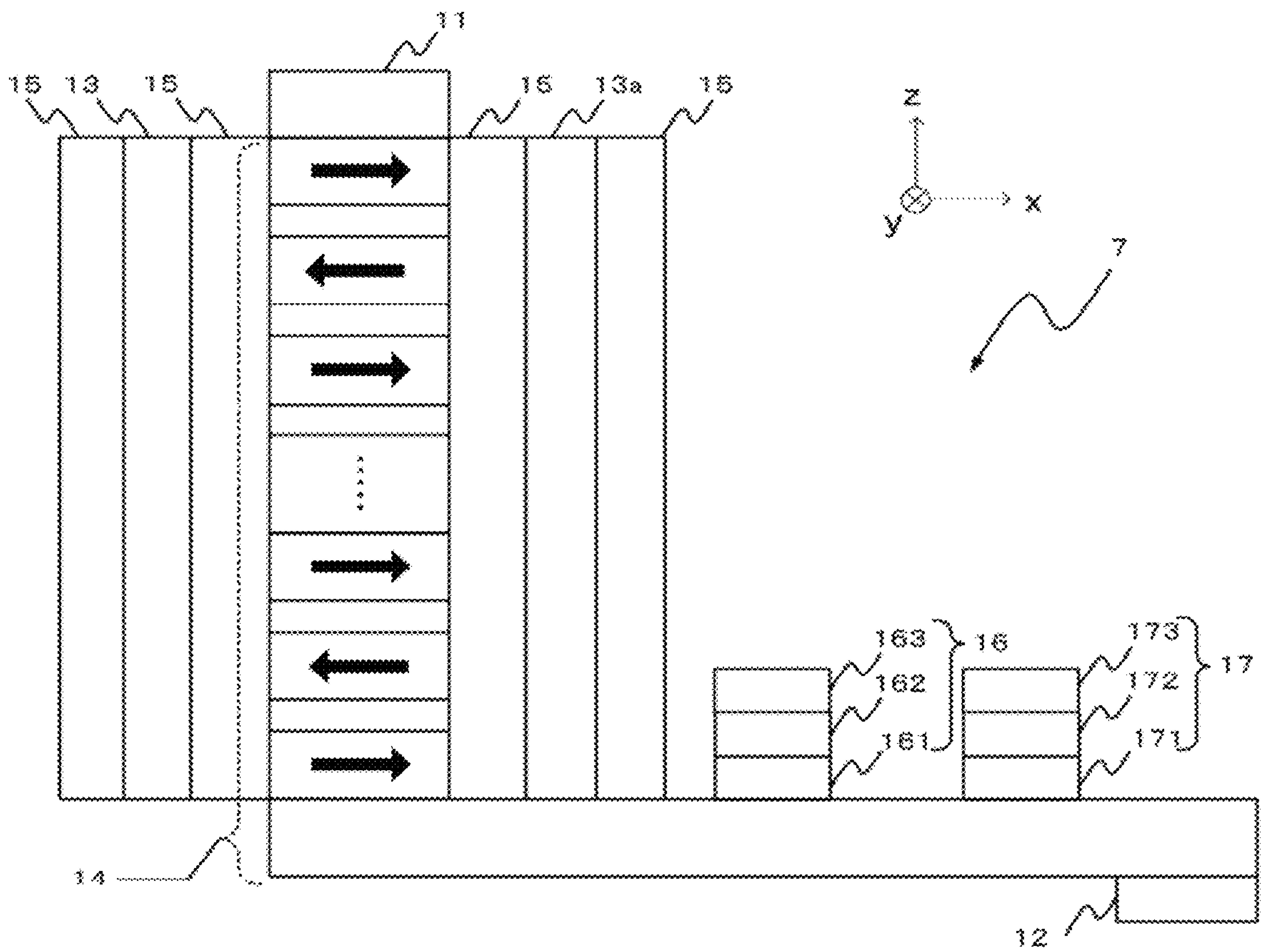


FIG.15B

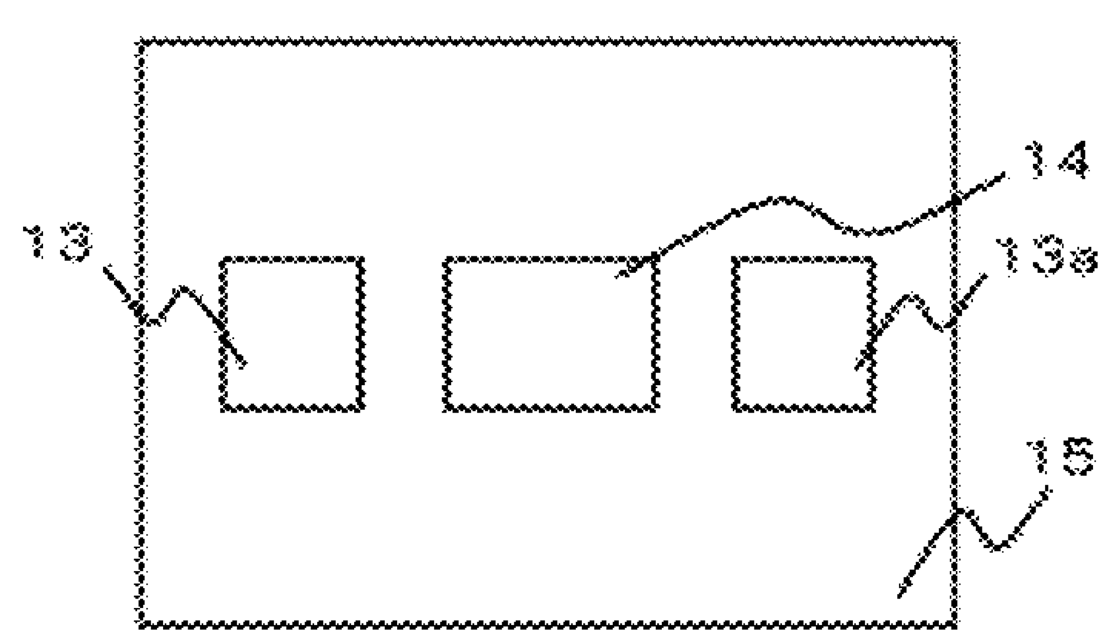


FIG.16A

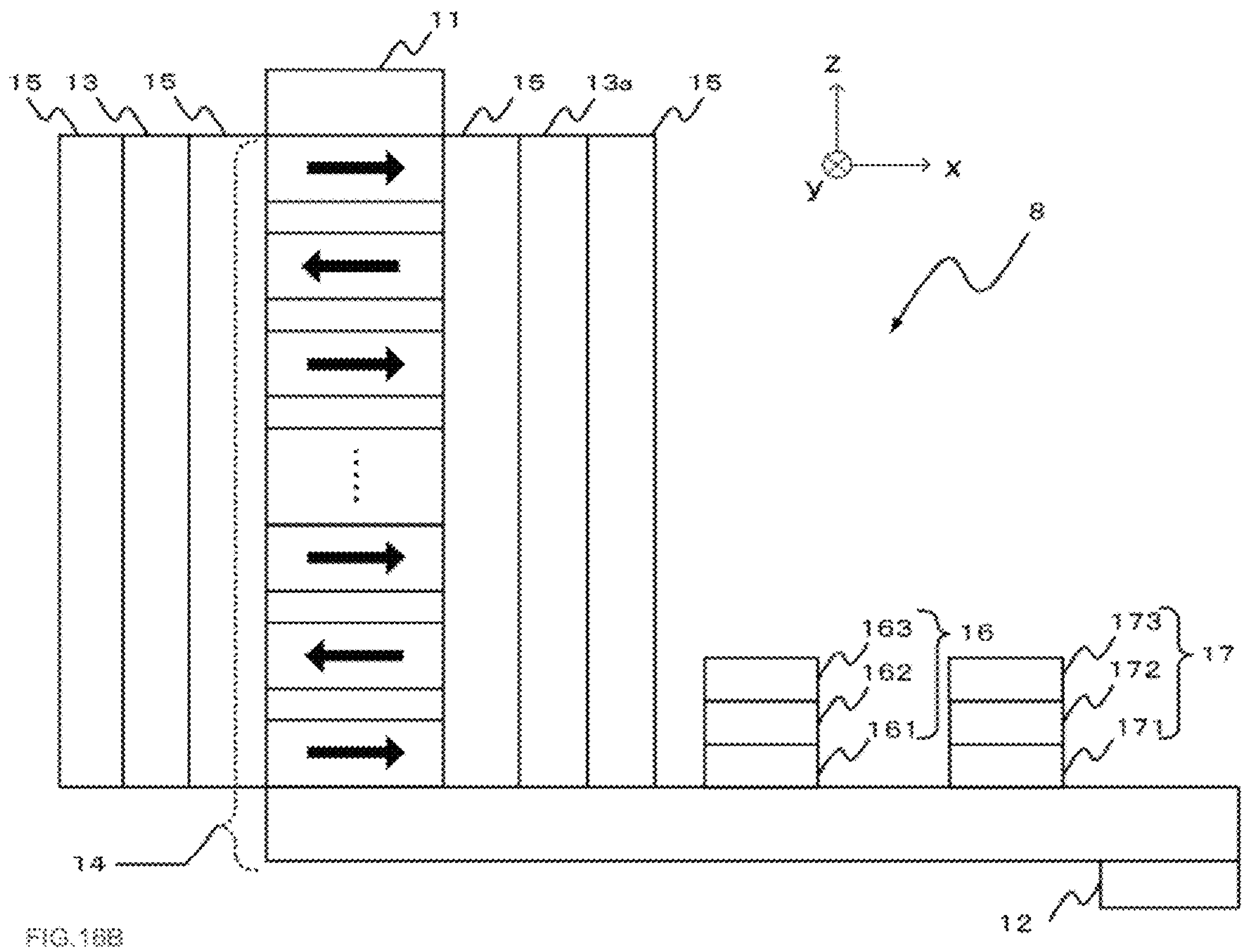


FIG.16B

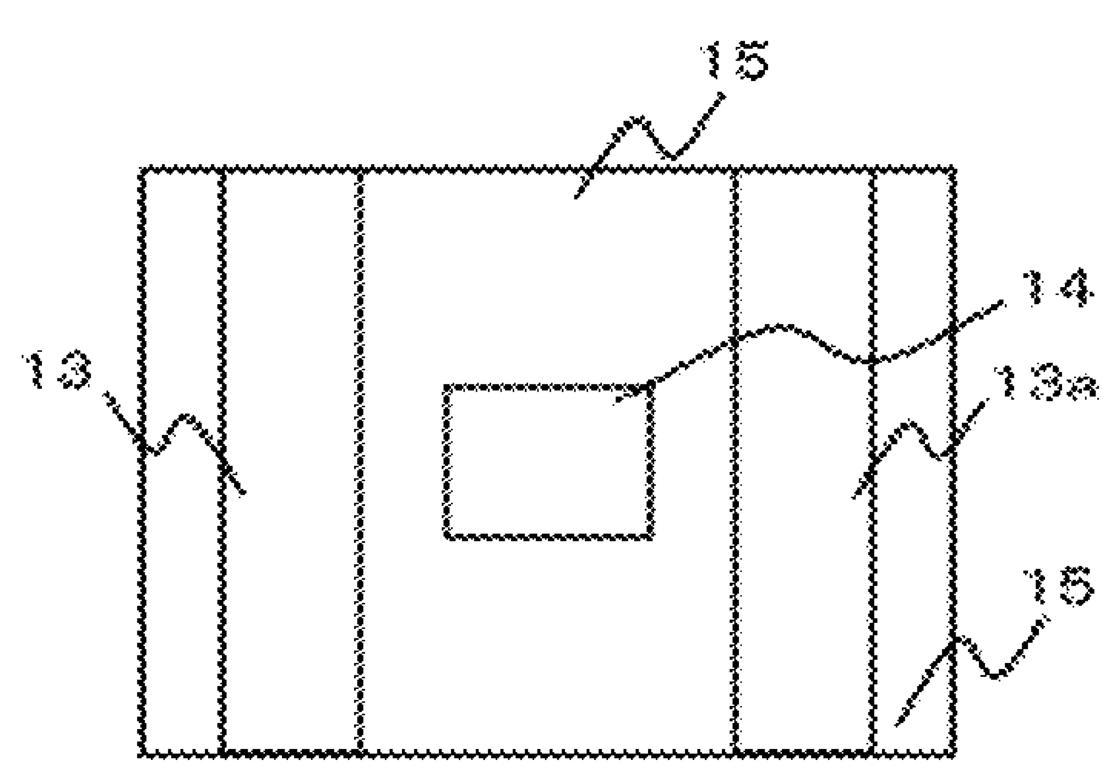


FIG. 17

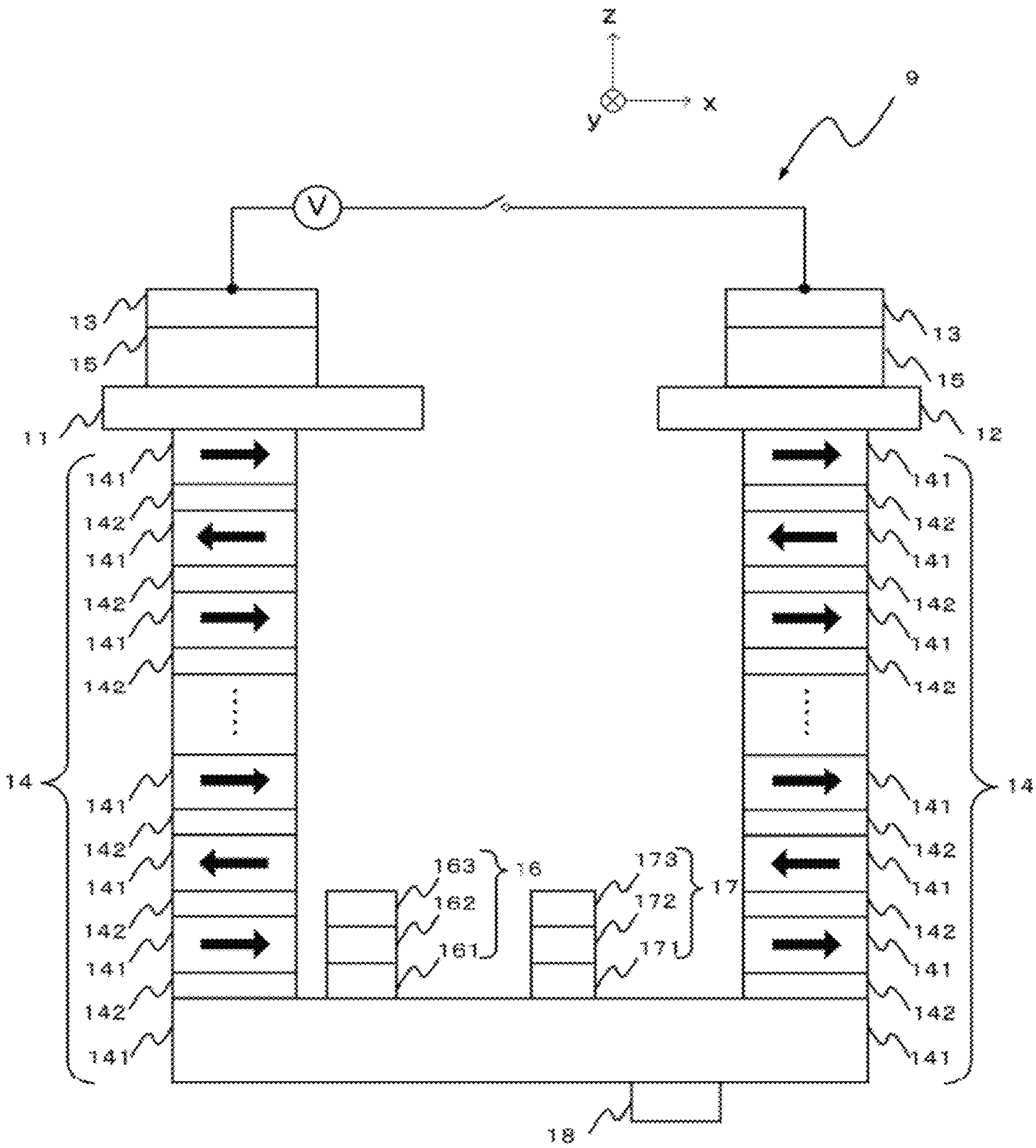


FIG. 18

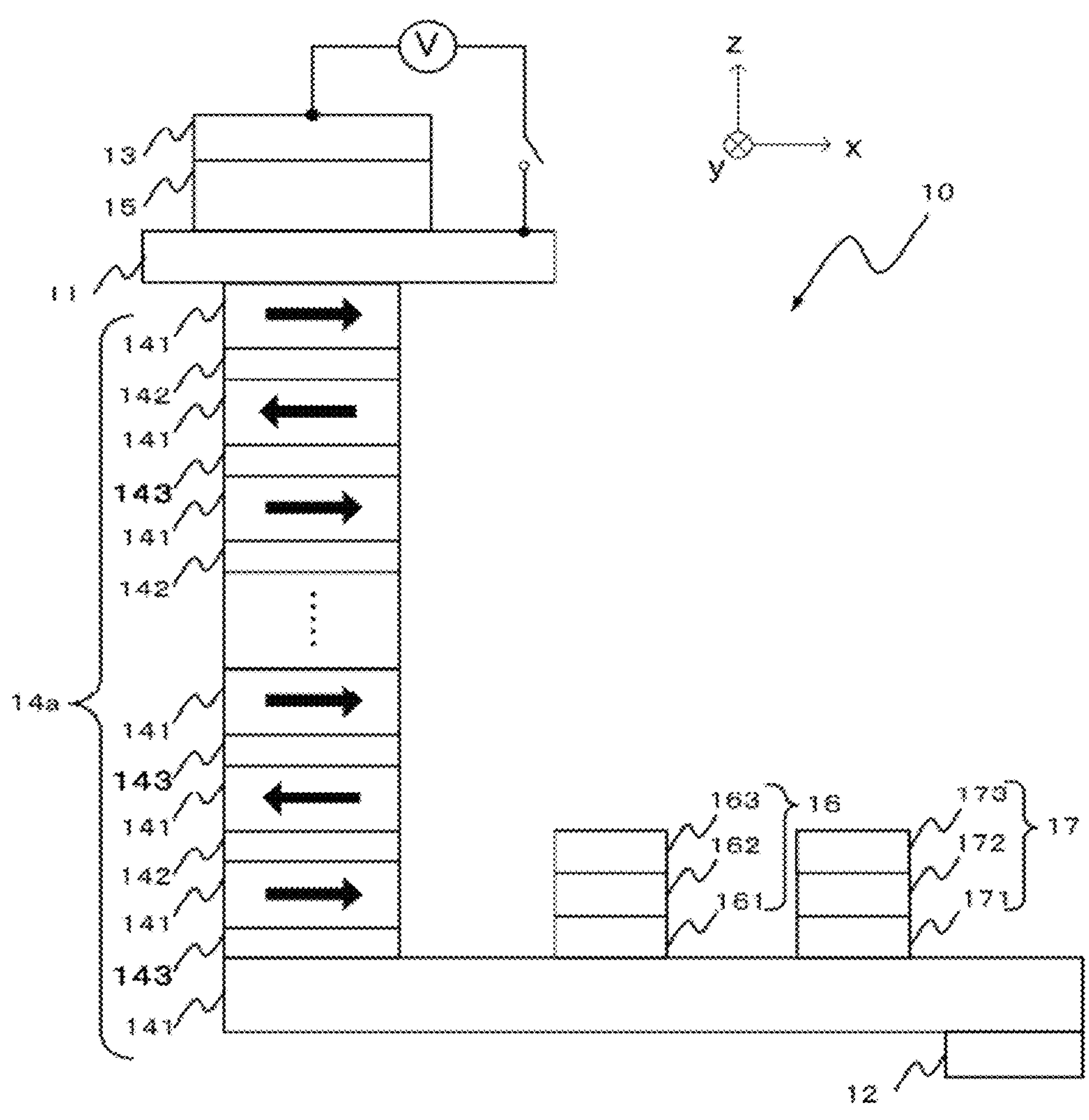

V
Z
X
y
10
13
15
11
141
142
141
143
141
142
14a
141
143
141
142
141
143
141
163
162
161
16
173
172
171
17
12

FIG.19A

FIG.19B

FIG.19C

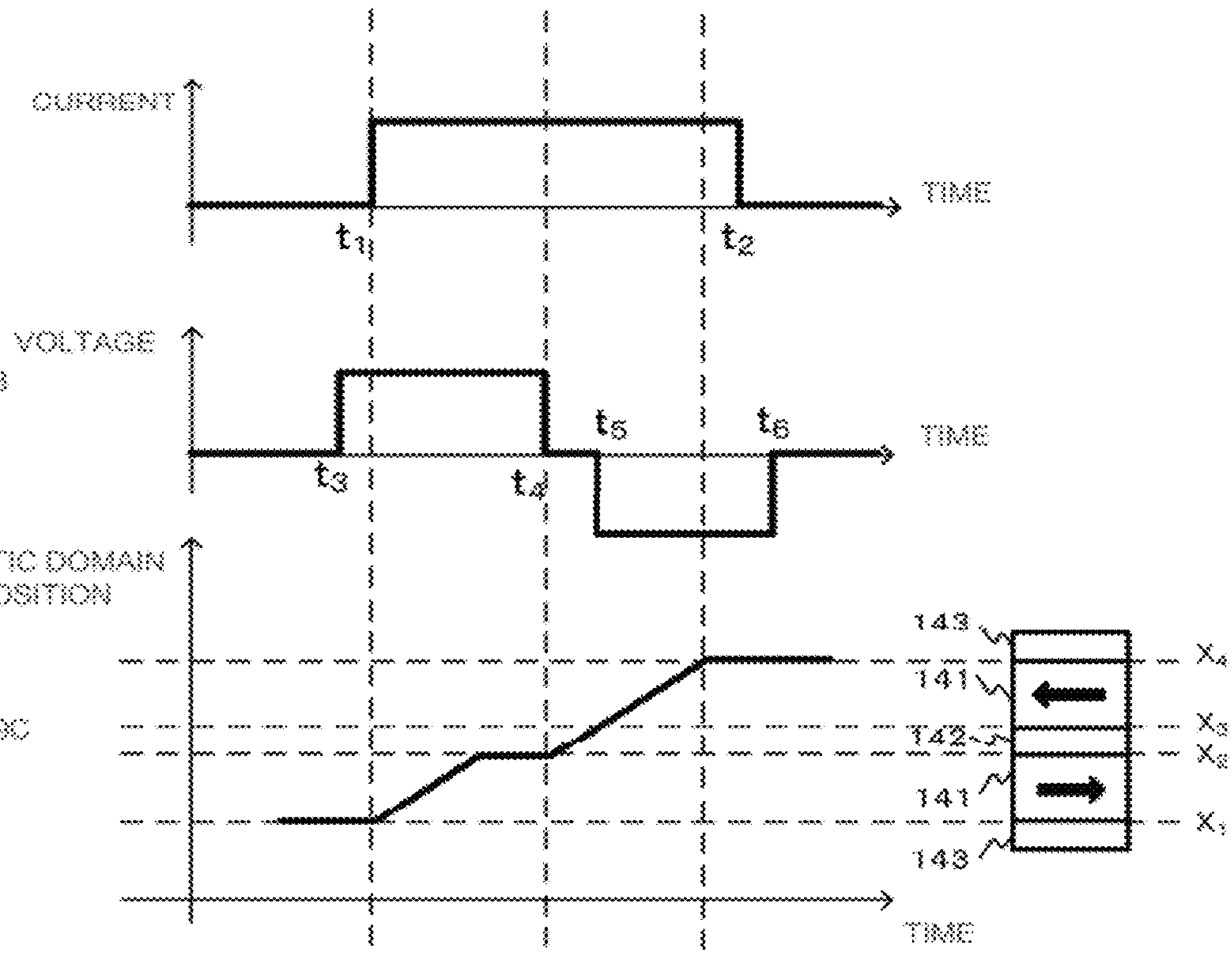
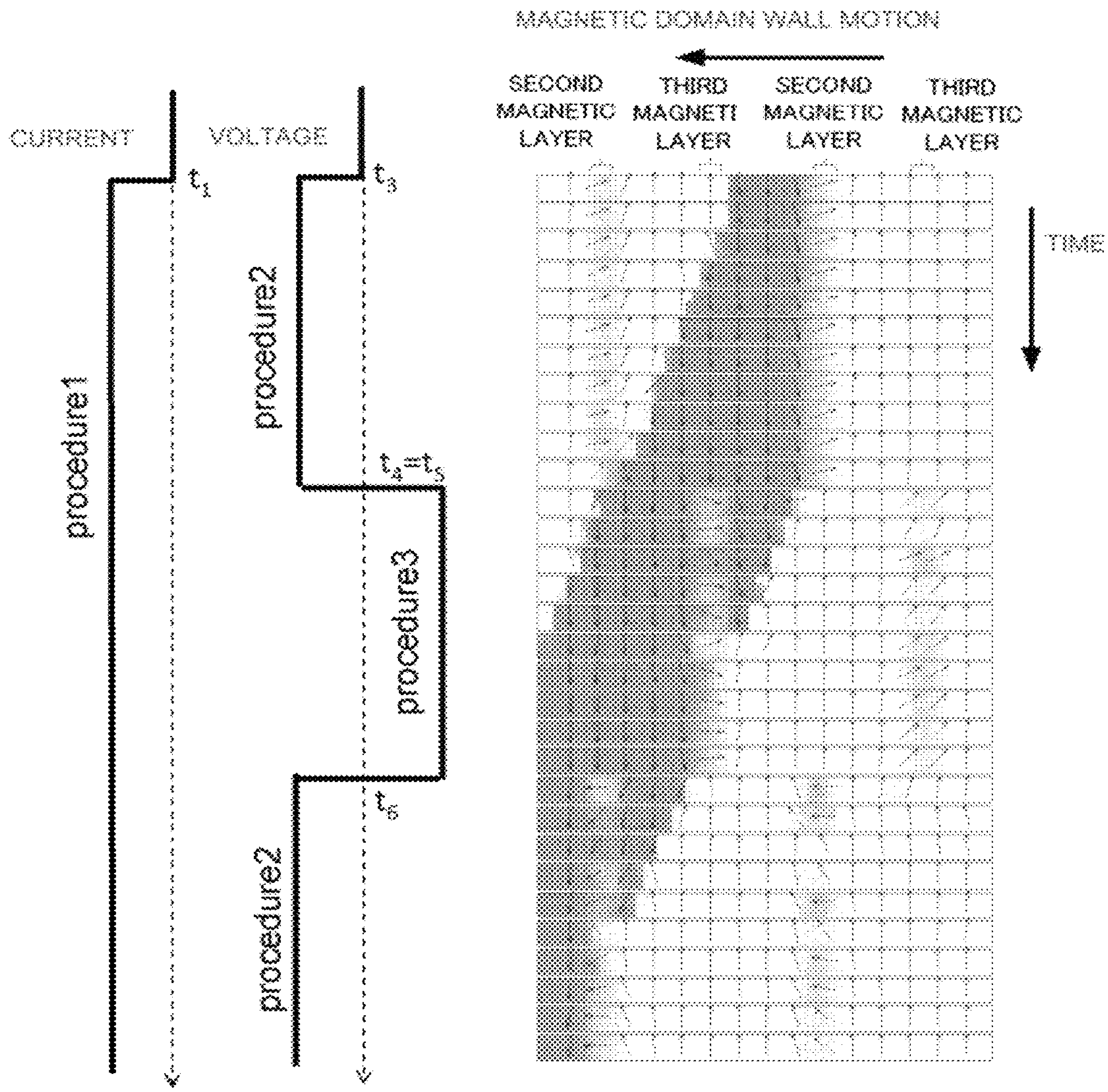
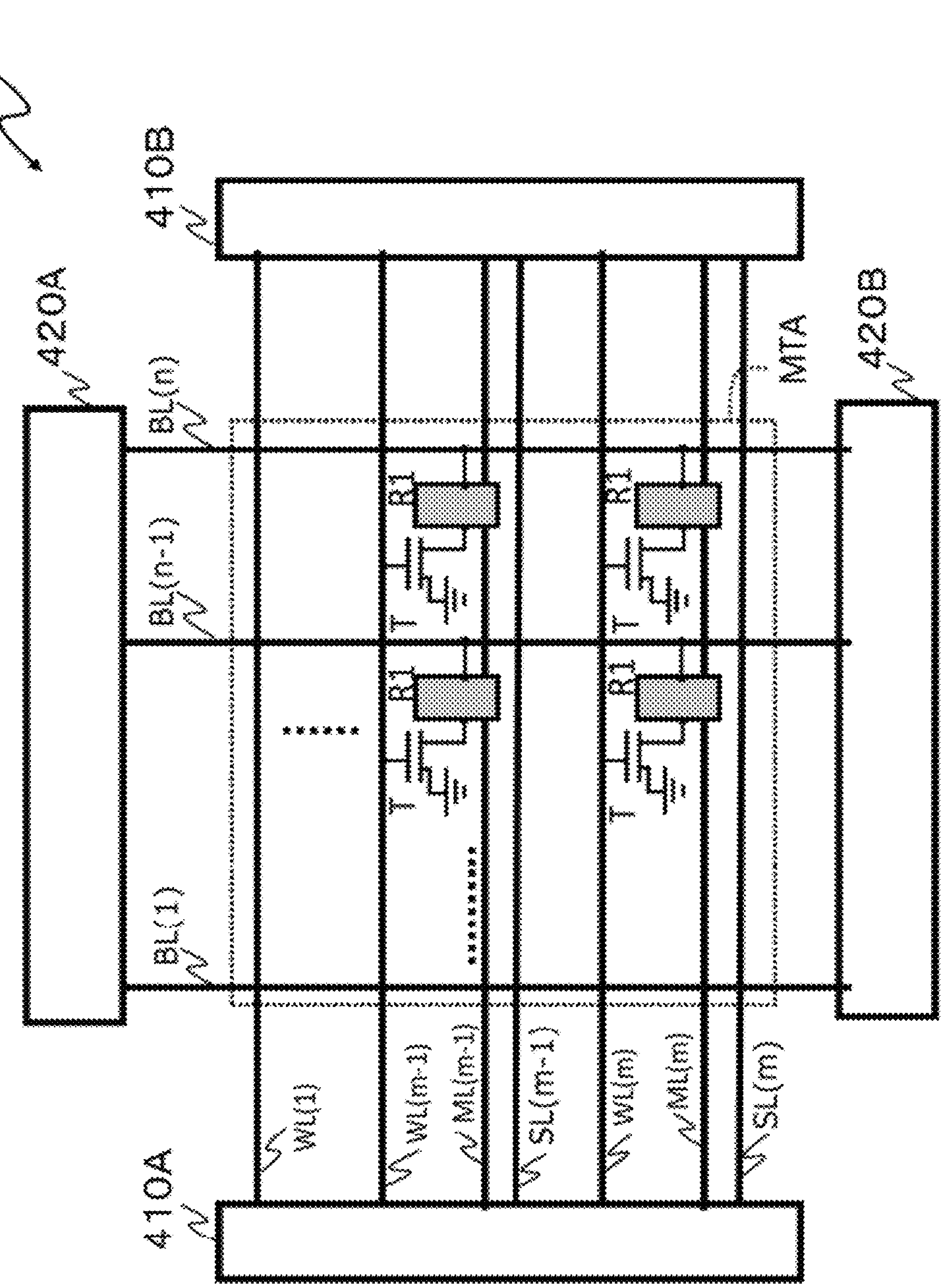


FIG.20A FIG.20B FIG.20C





50
410B
420A
420B
MTA
BL(n)
BL(m-1)
BL(1)
R1
T
WL(1)
WL(m-1)
ML(m-1)
SL(m-1)
WL(m)
ML(m)
SL(m)
410A

FIG.21

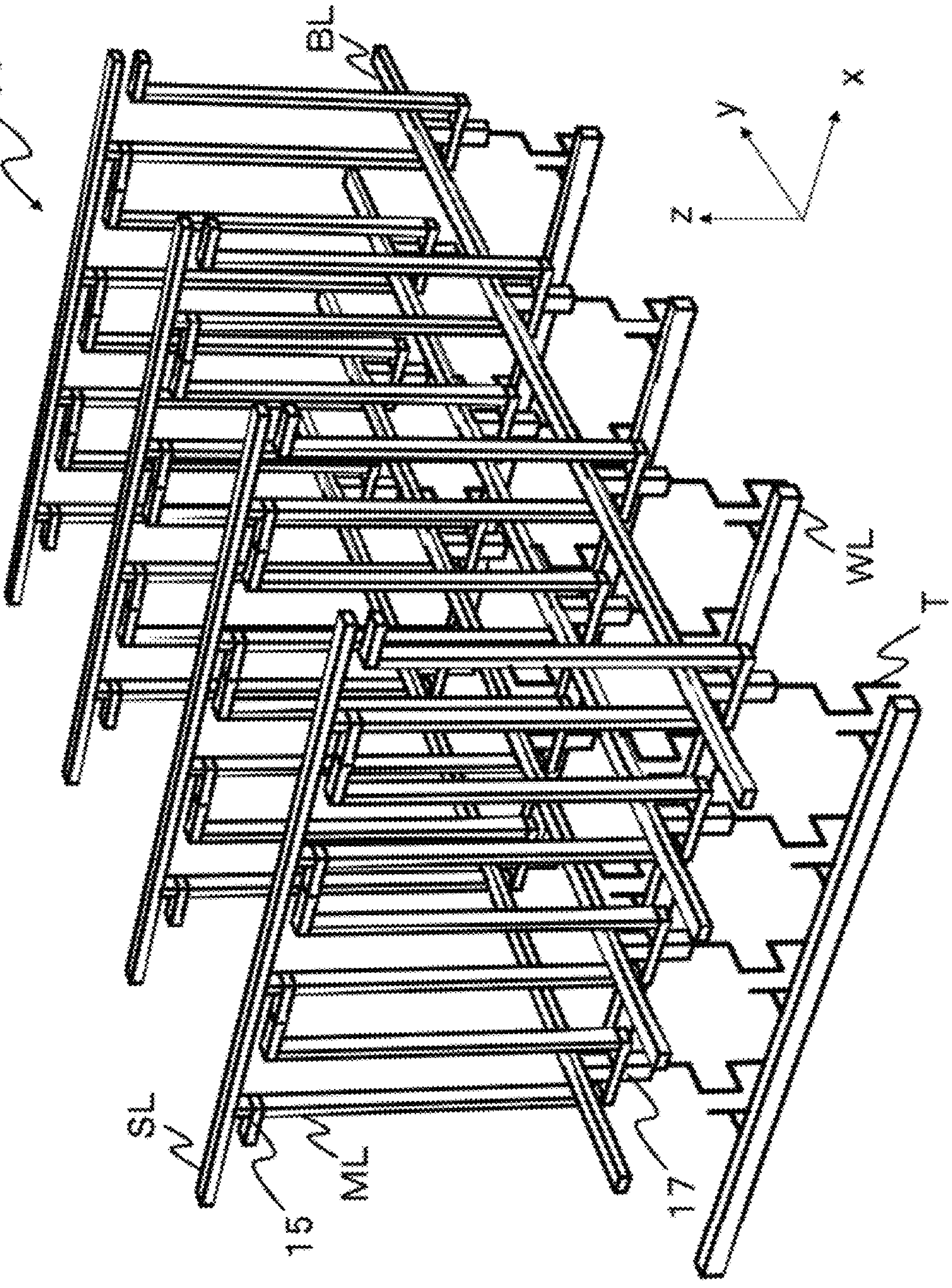


FIG.22

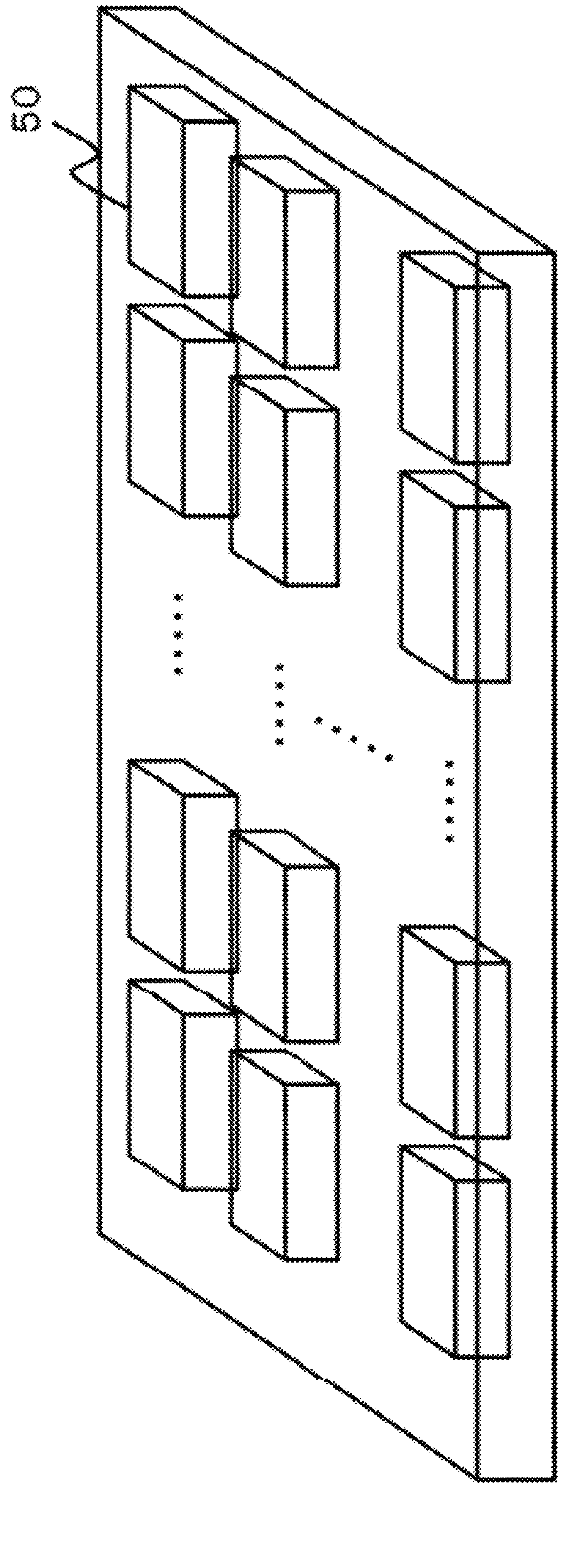


FIG.23

FIG.24

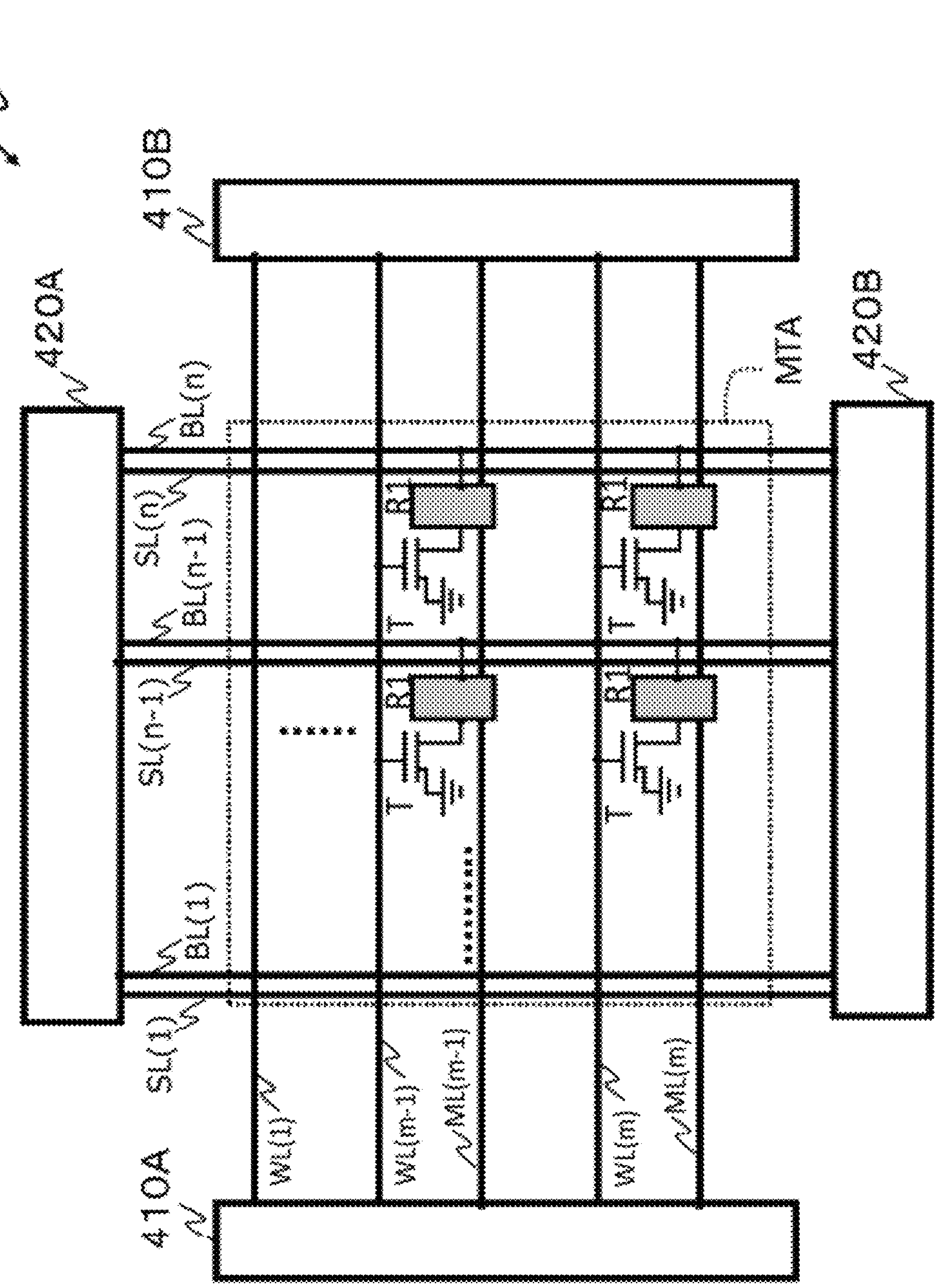
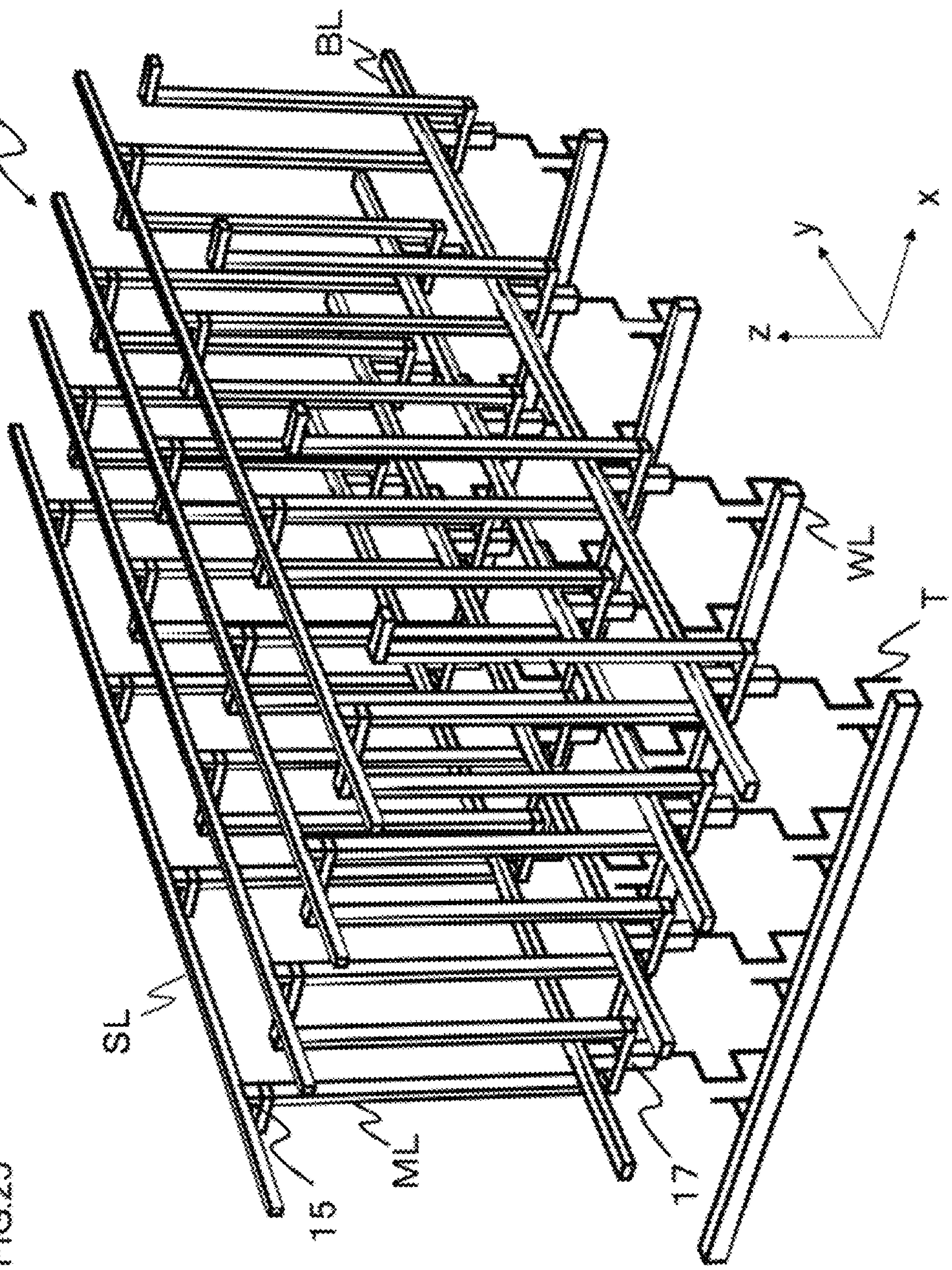

51
410A
410B
420A
420B
MTA
BL(n)
SL(n)
BL(n-1)
SL(n-1)
BL(1)
SL(1)
WL(1)
WL(m-1)
ML(m-1)
WL(m)
ML(m)
R1
T

FIG.25



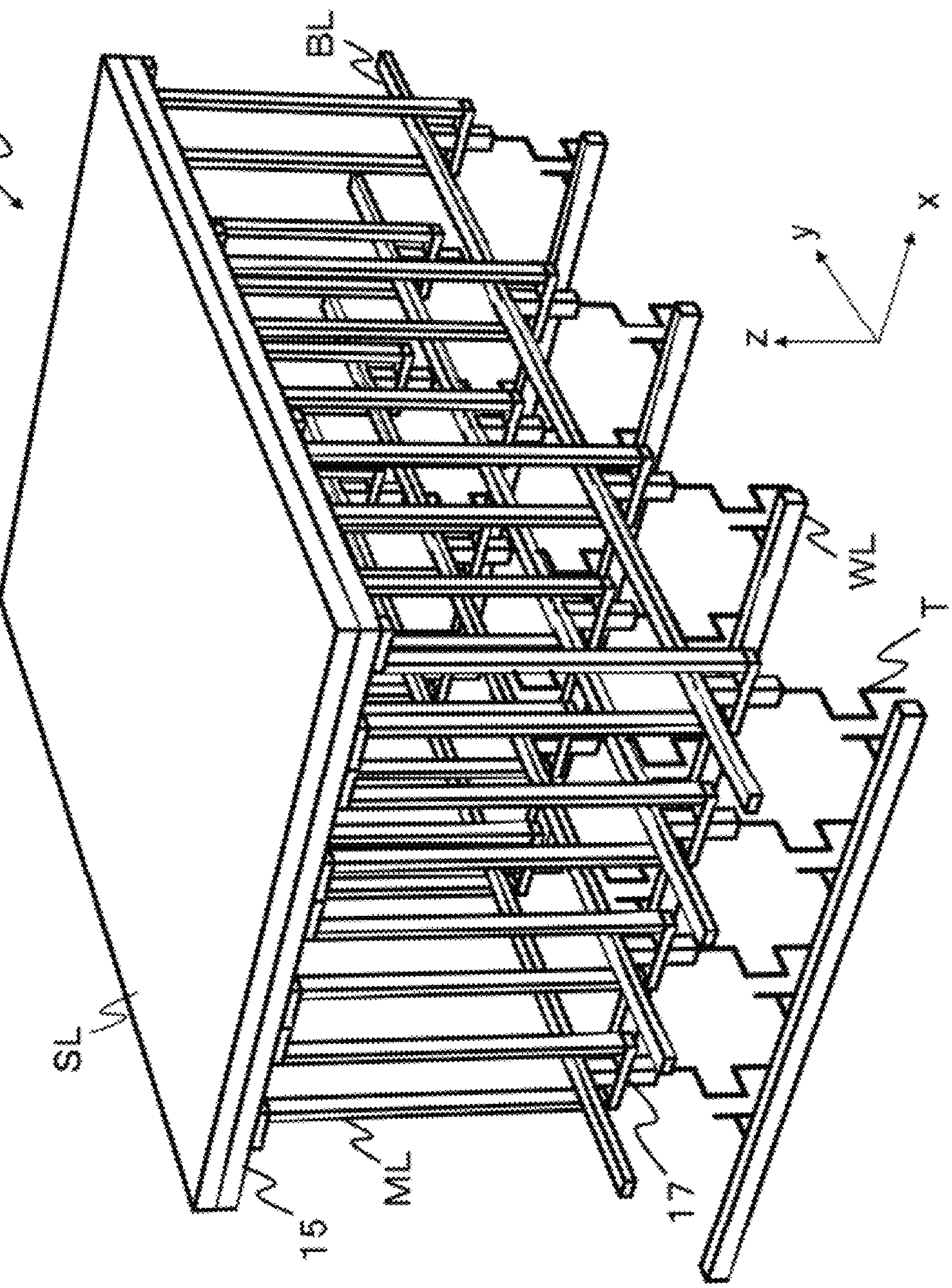
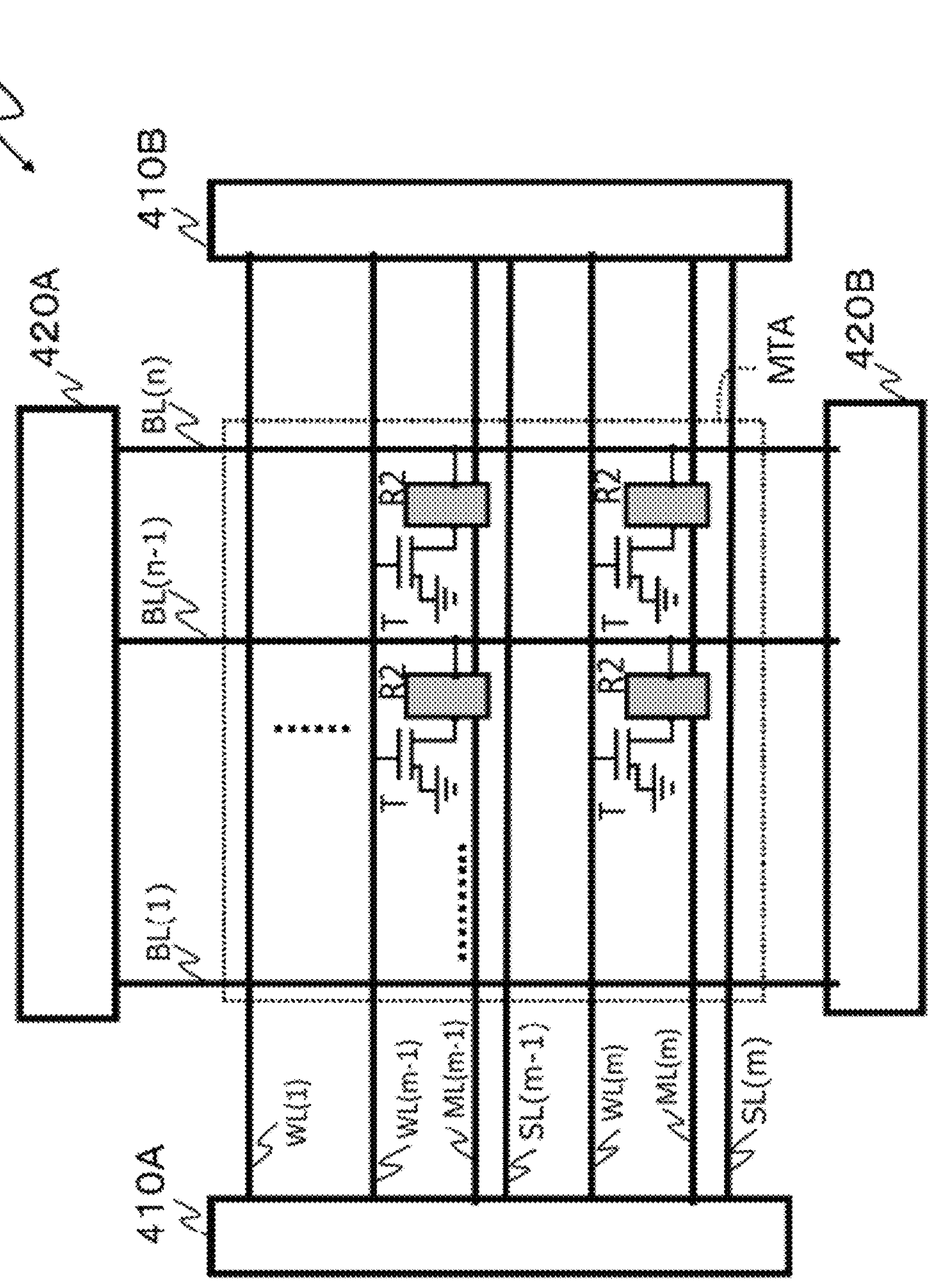


FIG.26

FIG.27


60
410A
410B
420A
420B
MTA
BL(1)
BL(n-1)
BL(n)
WL(1)
WL(m-1)
ML(m-1)
SL(m-1)
WL(m)
ML(m)
SL(m)
T
R2

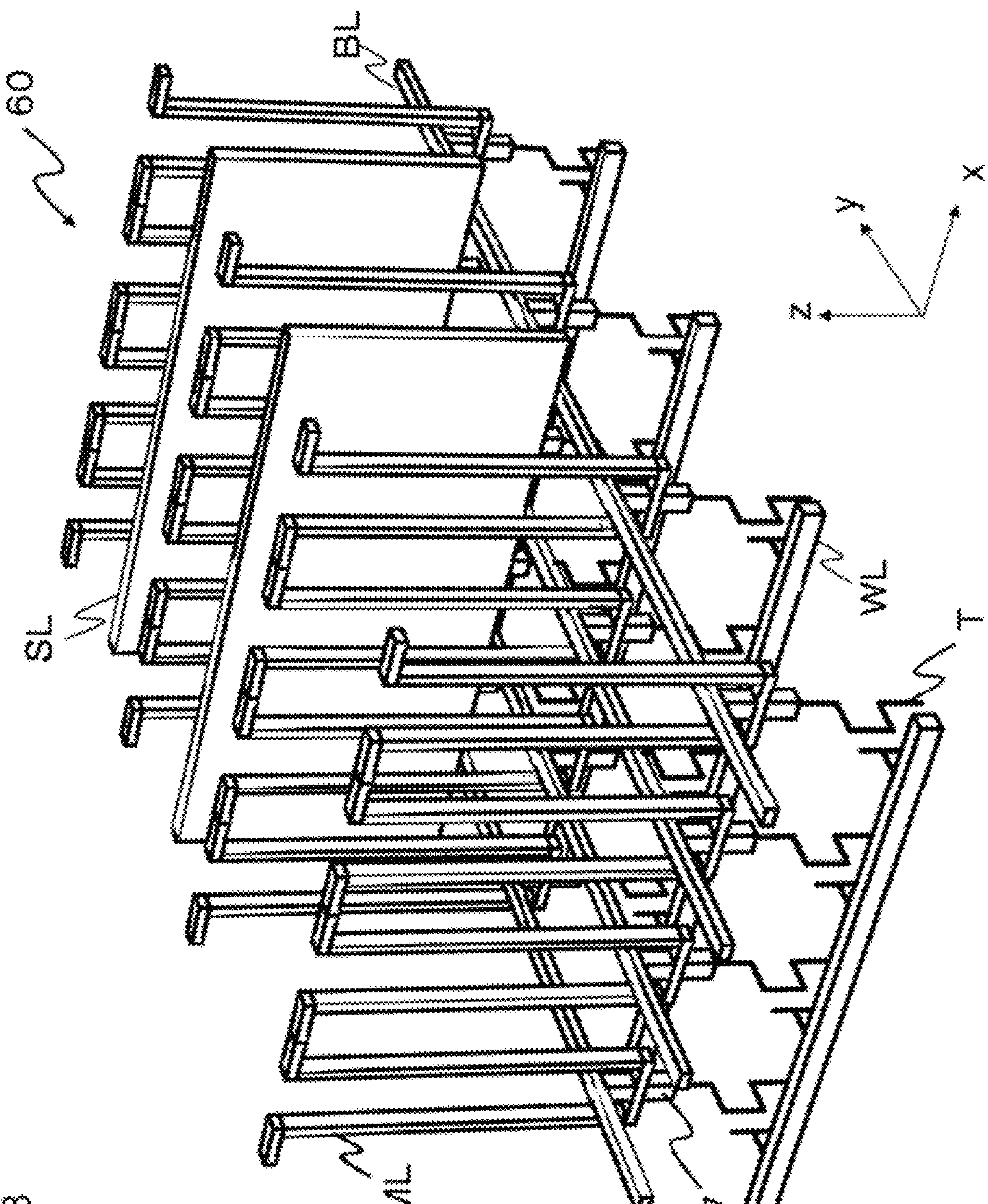
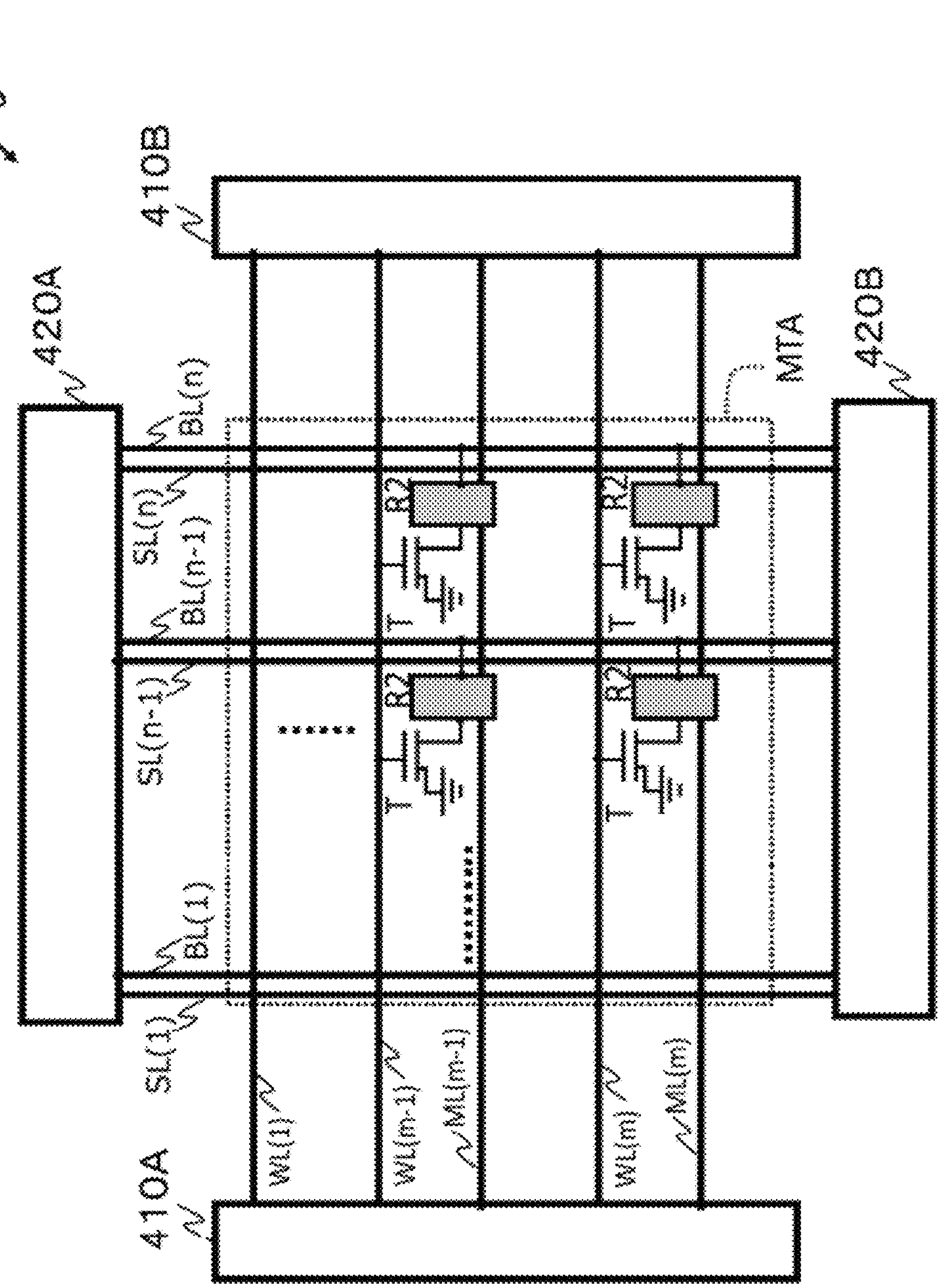


FIG.28

FIG.29


61
410B
420A
420B
MTA
BL(n)
SL(n)
BL(n-1)
SL(n-1)
BL(1)
SL(1)
R2
T
WL(1)
WL(m-1)
ML(m-1)
WL(m)
ML(m)
410A

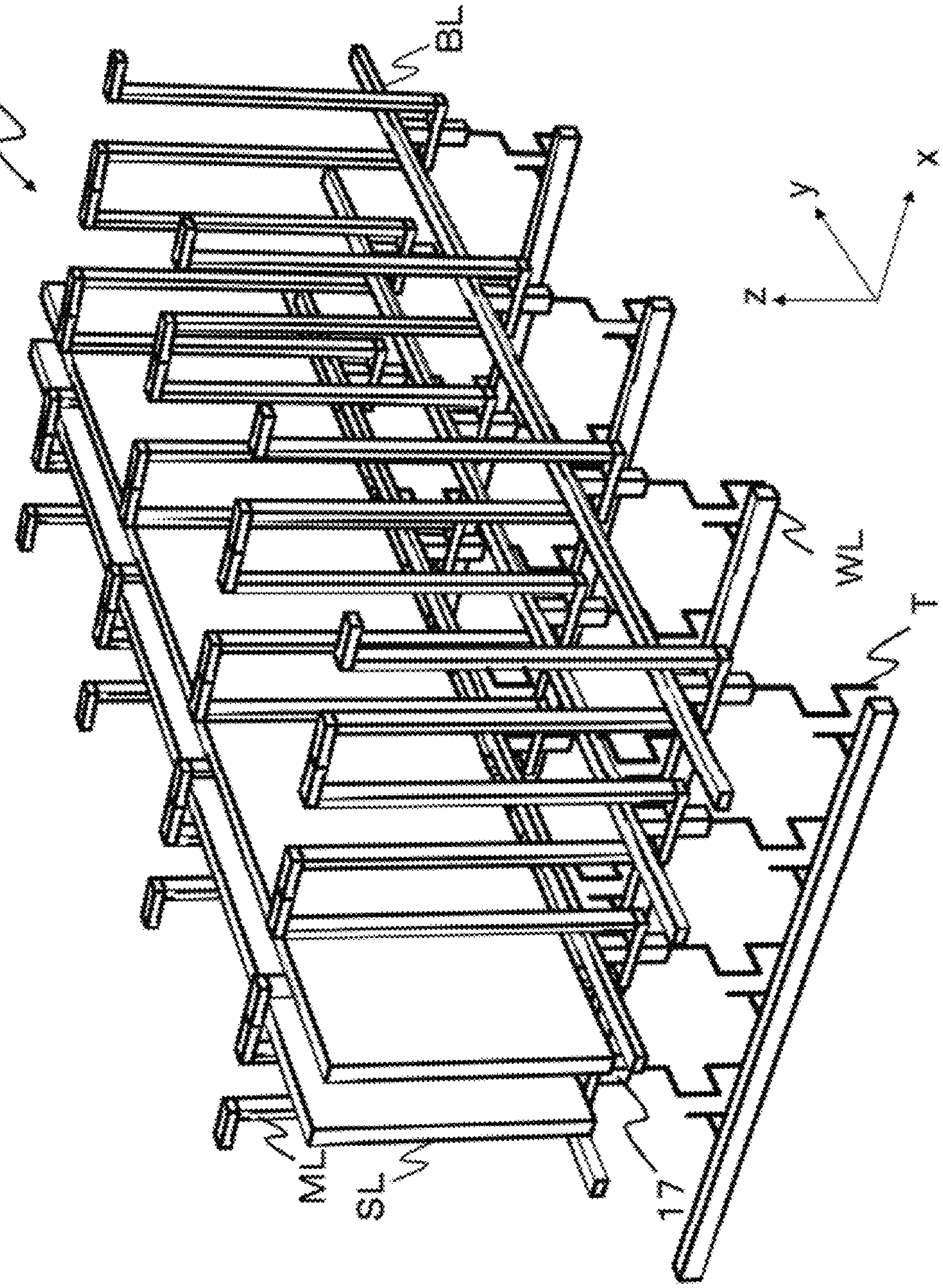


FIG.30

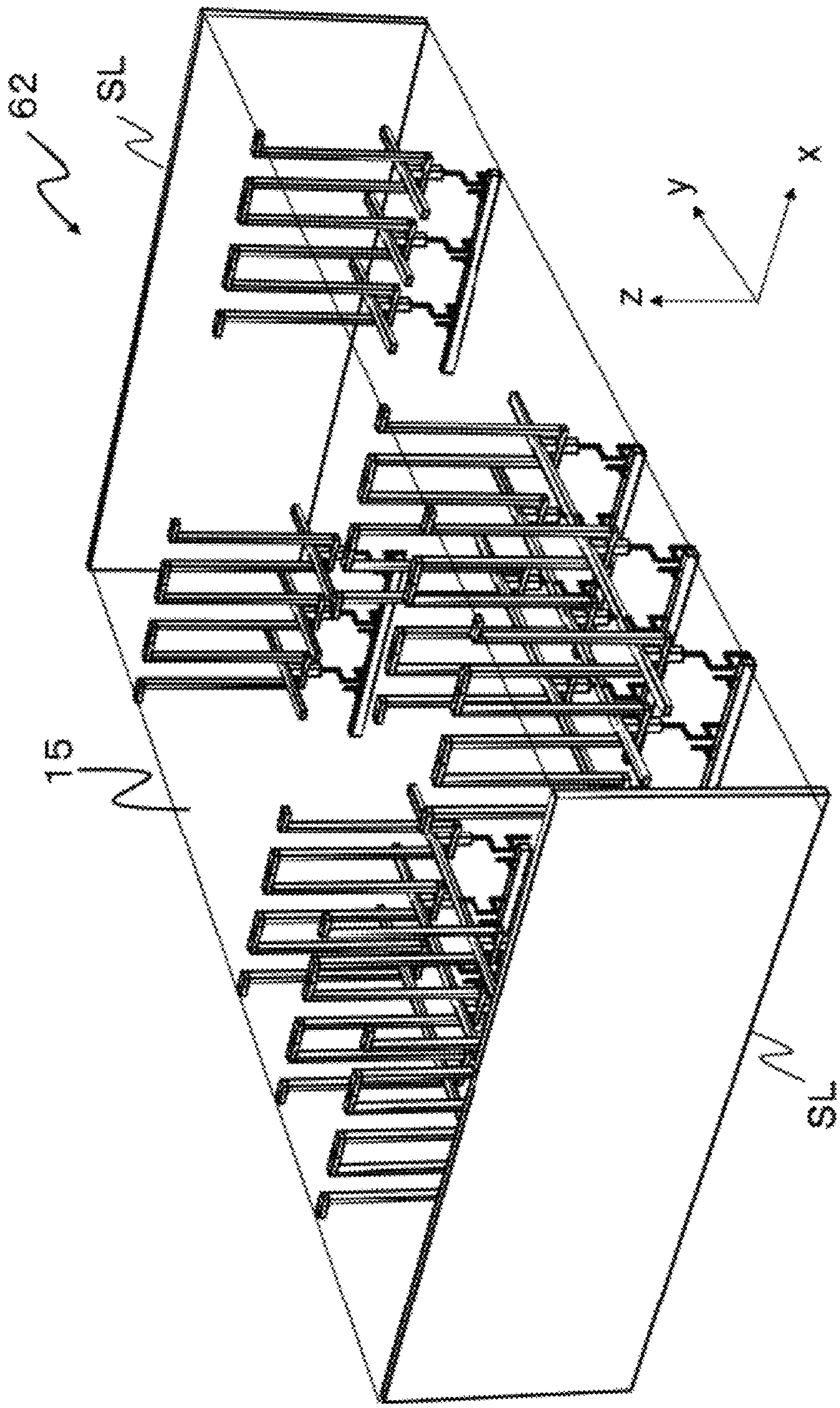


FIG.31

MAGNETIC MEMORY DEVICE AND METHOD OF MAGNETIC DOMAIN WALL MOTION

CROSS REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2011-076416, filed on Mar. 30, 2011 the entire contents of which are incorporated herein by reference.

FIELD

Embodiments described herein are related to a magnetic memory device, magnetic memory apparatus, and method of magnetic domain wall.

BACKGROUND

"A memory device, a selection device, and a wire which reads information" were fabricated in a semiconductor device. On the contrast, shift resistor type memory has been proposed for realizing a large capacity memory. This idea is based on arraying only the memory devices for realizing high density memory, and this idea is a method for transferring memory information to a sensor and a wire which are formed in given place. Thus, this idea enables memory capacity to increase markedly. The shift resister memory which is equipped with control electrode for each bit (digit) is not good as the use of memory, and several digits of shift motion should be operated by the shift resister memory by applying some actions to whole bit lines. However it is not easy for the shift resister to send whole digit information correctly.

BRIEF DESCRIPTION OF THE DRAWINGS

Aspects of this disclosure will become apparent upon reading the following detailed description and upon reference to the accompanying drawings. The description and the associated drawings are provided to illustrate embodiments of the invention and not limited to the scope of the invention.

FIG. **1** is a schematic view showing a cross section of a magnetic memory device of a first embodiment.

FIG. **2** is a view showing an example of sequences of magnetic domain wall motion of a magnetic memory device of a first embodiment.

FIG. **3** is a view showing an example of sequences of magnetic domain wall motion of a magnetic memory device of a first embodiment.

FIG. **4** is a view showing an example of sequences of magnetic domain wall motion of a magnetic memory device of a first embodiment.

FIG. **5** is a view showing an example of sequences of magnetic domain wall motion of a magnetic memory device of a first embodiment.

FIG. **6** is a schematic view showing a modified example of cross section of a magnetic memory device of a first embodiment.

FIG. **7** is a schematic view showing a modified example of cross section of a magnetic memory device of a first embodiment.

FIG. **8** is a schematic view showing a modified example of cross section of a magnetic memory device of a first embodiment.

FIG. **9** is a schematic view showing a modified example of cross section of a magnetic memory device of a first embodiment.

FIG. **10** is a schematic view showing a modified example of cross section of a magnetic memory device of a first embodiment.

FIG. **11** is a schematic view showing a modified example of cross section of a magnetic memory device of a first embodiment.

FIG. **12** is a schematic view showing a modified example of cross section of a magnetic memory device of a first embodiment.

FIG. **13** is a schematic view showing a modified example of cross section of a magnetic memory device of a first embodiment.

FIG. **14** is a schematic view showing a modified example of cross section of a magnetic memory device of a first embodiment.

FIG. **15** is a schematic view showing a modified example of cross section of a magnetic memory device of a first embodiment.

FIG. **16** is a schematic view showing a modified example of cross section of a magnetic memory device of a first embodiment.

FIG. **17** is a schematic view showing a modified example of cross section of a magnetic memory device of a first embodiment.

FIG. **18** is a schematic view showing a magnetic memory device in a second embodiment.

FIG. **19** is a view showing an example of sequences of magnetic domain wall motion of a magnetic memory device of a second embodiment.

FIG. **20** is a view showing a simulation result of a magnetic memory device of a second embodiment.

FIG. **21** is a view showing a block circuit of a third embodiment.

FIG. **22** is a schematic view showing a block of a third embodiment.

FIG. **23** is a schematic view showing memory tip of an embodiment.

FIG. **24** is a view showing a block circuit of a first modified example of a third embodiment.

FIG. **25** is a schematic view showing a block of a first modified example of a third embodiment.

FIG. **26** is a schematic view showing a block of a second modified example of a third embodiment.

FIG. **27** is a view showing a block circuit of a fourth embodiment.

FIG. **28** is a schematic view showing a block of a fourth embodiment.

FIG. **29** is a block circuit showing a first modified example of a third embodiment.

FIG. **30** is a schematic view showing a first modified example of a third embodiment.

FIG. **31** is a schematic view showing a second modified example of a third embodiment.

DETAILED DESCRIPTION

Embodiments will be described below with reference to drawings. Wherever possible, the same reference numerals or marks will be used to denote the same or like portions throughout figures, and overlapped explanations are omitted in embodiments following a first embodiment.

First Embodiment

FIG. **1** shows a schematic view showing a cross section of a magnetic memory device of a first embodiment. The magnetic memory device **1** is provided on a substrate, and the magnetic memory device **1** comprises a first electrode **11**, a second electrode **12**, a third electrode **13**, a laminated structure **14**, a piezoelectric body **15**, a writing section **16**, and a reading section **17**.

The laminated structure **14** comprises multilayer that a first magnetic layer **141** and a second magnetic layer **142** are laminated alternately, and the laminated structure **14** is formed like a wire between the first electrode **11** and the second electrode **12**. The second magnetic layer **142** can be formed in contact with the first electrode **11** although the first magnetic layer **141** is formed in contact with the first electrode **11** in FIG. **1** A cross sectional shape cutting the first magnetic layer **141** and the second magnetic layer **142** in laminating direction, which corresponds to z-direction in FIG. **1** and is also called as z-direction, is rectangular shape, for example. The cross sectional shape is not limited for the rectangular shape, but the cross sectional shape is notable to be square, rectangle, polygon (hexagonal shape, for example), circle, ellipse, rhombus, or parallelogram. Aspect ratio of these shapes is from 1 to 1 to 1 to 4. The first magnetic layer **141** and the second magnetic layer **142** are comprised of different composition of constituent element each other. Magnetostriction constant of the first magnetic layer **141** has different sign from magnetostriction constant of the second magnetic layer **142**. Or absolute value of the magnetostriction constant of the first magnetic layer **141** is smaller than the magnetostriction constant of the second magnetic layer **142** in the case where sign of the magnetostriction constant of the first magnetic layer **141** is different from sign of the magnetostriction constant of the second magnetic layer **142**.

In-plane size, referring to a size which is parallel to z-direction, of the first magnetic layer **141** and the second magnetic layer **142** is markedly equal to or less than 100 nm not to generate inhomogeneous distribution of magnetization direction. Bit data is memorized as magnetization direction of given distance in the laminated structure **14** of the magnetic memory device in laminating direction. Typically one bit data per one first magnetic layer is reserved. Two or more bits data can be reserved in the magnetic memory device. However, one bit data per one first magnetic layer is reserved following description.

In FIG. **1** and following schematic figures, only several of the first magnetic layers **141** and the second magnetic layers **142** are shown in the laminated structure **14**. However actual laminated structure **14** comprises much more the first magnetic layers **141** and the second magnetic layers **142** to be able to reserve from 100 bits data to several thousands data. The longer the whole length of the laminated structure **14** is, the laminated structure **14** can comprise more the second magnetic layers **142** and reserve a lot of bits data. However, the whole length of the laminated structure **14** is typically from 100 nm or more to 10 μm or less.

As mentioned above, the laminated structure **14** comprises a lot of magnetic domains, corresponding to bit data which is reserved in the magnetic memory device, in the laminated structure **14**. At the border of two neighbouring magnetic domains, magnetization direction changes in laminating direction continuously. This changing region in magnetization direction is called magnetic domain wall. The magnetic domain wall has a finite width 'w' which is determined by the anisotropic energy or exchange stiffness of magnetic material.

The magnetization direction is not uniform in one first magnetic layer **141** when current is not applied to the laminated structure **14**. Thus, the magnetic domain wall generates near the boundary between the first magnetic layer **141** and the second magnetic layer **142** when the magnetization directions of two first magnetic layers **142** sandwiching the second magnetic layer **142** are different. The width of the magnetic domain wall 'w' is described as $w=(A/Ku)^{1/2}$. As typical value, A=1 μerg/cm, $Ku=10^7$ erg/cm^3, and w=3 nm. The magnetic domain wall can be controlled easily in the second magnetic layer **142** when each layer thickness of the second magnetic layer **142** is larger than the width of the magnetic domain wall 'w' and is twice as small as the width of the magnetic domain wall 'w'. The magnetic memory device **1** enables to increase the ratio accounting for the magnetic layer **141** in the laminated structure **14**. Thus the magnetic memory device **1** enables to increase the amount of memory information if the laminated structure **14** is regarded as the memory area in memory device. Each thickness of the first magnetic layer **141** is needed to be larger than the width of the magnetic domain wall 'w'. If the thickness of the first magnetic layer **141** is third times larger than the width of the magnetic domain wall, the volume of the area except for the magnetic domain wall is twice larger than the volume of the area of the magnetic domain wall, and the magnetization state can be reserved easily even if the magnetic domain wall exists in the first magnetic layer **141**.

The magnetization direction of the first magnetic layer **141** and the magnetization direction of the second magnetic layer **142** neighboring the first magnetic layer **141** are substantially parallel or antiparallel to each other except for the area of the magnetic domain wall when voltage is not applied to the piezoelectric body **15**.

A piezoelectric body **15** is provided on prolonged line which connects plural of the first magnetic layers **141** and the second magnetic layers **142**. For example, in FIG. **1** the piezoelectric body **15** is provided between the first electrode **11** and the third electrode **13**. One face of the piezoelectric body **15** is connected to the face opposite to the face where the first electrode **11** is connected to the laminated structure **14**. The face, opposite to the face where the piezoelectric body **15** is connected to the first electrode **11**, is connected to the third electrode **13**.

Voltage can be applied between the first electrode **11** and the third electrode **13**. A current source, which is not shown in figure, is connected between the first electrode **11** and the second electrode **12** and the current source enables to pass current in the laminated structure bi-directionally.

A writing section **16** comprises a nonmagnetic layer **161** and a ferromagnetic layer **162**, and an electrode **163** and is connected to the laminated structure **14**. A signal source, which is not shown in figure, is connected to the electrode **163**. Voltage is applied to the electrode **163** from the signal source in order to write information in the magnetic memory device **1**. In that case, spin-polarized electron flow passes in magnetization direction of the ferromagnetic layer **162** when electron passes from the electrode **163** to the laminated structure **14**. The spin-polarized current flow makes the magnetization direction of the laminated structure **14** changed.

A reading section **17** comprises a nonmagnetic layer **171**, ferromagnetic layer **172**, and an electrode **173** and is connected to the laminated structure **14**. In the case where the magnetization direction of the magnetic domain being connected with the reading section **17** of the laminated structure **14** is orientated in the same direction (parallel) to the magnetization direction of the ferromagnetic layer **172**, a low-resistive state is generated between the electrode **173** and the second electrode **172**. In the case where the magnetization direction of the magnetic domain being connected with the reading section **17** of the laminated structure **14** is orientated in the opposite direction (antiparallel) to the magnetization direction of the ferromagnetic layer **172**, a high-resistive state is generated between the electrode **173** and the second electrode **12**. Recorded information can be read by these resistance changes.

The magnetic memory device **1** enables to move bit data which is reserved in the laminated structure **14** without changing the order of the bit data by using following the magnetic domain wall motion steps. Thus before writing action and reading action, given bit data can be read and written in given position by moving the magnetic domain wall position at sufficient distance preliminarily.

Steps which move the magnetic domain wall in the laminated structure **14** of the magnetic memory device **1** at given distance in z-direction are explained. These steps comprise two steps. First step (step 1) is a step which passes current between the first electrode **11** and the second electrode **12** from time t1 to time t2 as shown in FIG. **2**A. Second step (step 2) is a step which applies voltage between the first electrode **11** and the third electrode **13** from time t2 to time t4.

When current is flown between the first electrode **11** and the second electrode **12** (step 1), current which flows in the laminated structure **14** is spin-polarized. The spin-torque acts on the magnetization of the first magnetic layer **141** and the second magnetic layer **142** which comprise the laminated structure **14**. For this reason, the magnetic domain wall in the laminated structure **14** moves. The direction of the magnetic domain wall motion is same as the direction of electron flow, which is opposite to the direction of current flow.

When voltage is applied between the first electrode **11** and the third electrode **13** (step 2), electric field is generated in the piezoelectric body **15** for the direction which connects first electrode **11** and the third electrode **13**. In this case, the piezoelectric body **15** extends in the direction which connects the first electrode **11** and the third electrode **13** when the direction of electric field is same as the direction of polarization of the piezoelectric body **15**. In contrast, the piezoelectric body **15** shrinks in the direction which connects the first electrode **11** and the third electrode **13** when the direction of electric field is opposite to the direction of polarization of the piezoelectric body **15**.

In this case, due to inverse-magnetostrictive effect, a magnetic anisotropy is induced by the strain applying to the second magnetic layer **142** in the laminated structure **14**. As a result, the magnetization direction of the second magnetic layer **142** changes from the state before starting the step 2.

As an example, the case, where the magnetization direction of the second magnetic layer **142** is oriented in the perpendicular direction (x-direction in FIG. **1**) to z-direction by magnetocrystalline anisotropy or like before starting the step 2, is explained. In the case where the magnetostriction constant of the second magnetic layer **142** is positive, elastic energy increases in the perpendicular direction to laminating direction by tensile strain in z-direction. For this reason, the magnetization direction of the second magnetic layer **142** turns in parallel (z-direction) to the laminating direction, for example, because it is difficult for the magnetization of the second magnetic layer **142** to be in x-direction magnetization direction of the second magnetic layer **142**. In the case where the magnetization coefficient of the second magnetic layer **142** is negative, elastic energy increases in x-direction by compressive strain in z-direction. For this reason, the magnetization direction of the second magnetic layer **142** turns in z-direction, for example, because it is difficult for the magnetization direction of the second magnetic layer **142** to be in x-direction.

When the strain is not applied to the laminated structure **14** after the step 2, the magnetic anisotropy of the second magnetic layer **142** returns to the state before the start of the step 2. Then, the magnetization direction of the second magnetic layer **142** turns to x-direction.

The strain corresponding to stretching of the piezoelectric body **15** by the step 2 is not only applied to the second magnetic layer **142** but also to the first magnetic layer **141**. However in this embodiment, the sign of the magnetostriction constant of the first magnetic layer **141** is different from the sign of the magnetostriction constant of the second magnetic layer **142**. Or the absolute value of the magnetostriction constant of the first magnetic layer **141** is smaller than the absolute value of the magnetostriction constant of the second magnetic layer **142** even if the magnetostriction constant of the first magnetic layer **141** is same as the magnetostriction constant of the second magnetic layer **142**.

For this reason, magnetization direction of the first magnetic layer **141** is unchanged. The two cases are explained to explain this phenomenon.

In the first case where the sign of the magnetostriction constant of the first magnetic layer **141** is opposite to the sign of the magnetostriction constant of the second magnetic layer **142**, the magnetization direction of the first magnetic layer **141** is unchanged because the elastic energy of the first layer decreases when the elastic energy increases in the x-direction of the second magnetic layer **142**, for example.

In the second case where the absolute value of the magnetostriction constant of the first magnetic layer **141** is smaller than the absolute value of the magnetostriction constant of the second magnetic layer **142** even if the magnetostriction constant of the first magnetic layer **141** is same as the magnetostriction constant of the second magnetic layer **142**, the magnetization direction of the first magnetic layer **141** is unchanged because the absolute value of the elastic energy which generates in the first magnetic layer **141** is small in the case where the elastic energy generates in x-direction of the second magnetic layer **142**.

The case, where the magnetization direction of the second magnetic layer **142** turns in z-direction by crystalline magnetic anisotropy and shape magnetic anisotropy before the start of the step 2 is same as above cases. In the case where the magnetostriction constant of the second magnetic layer **142** is positive, elastic energy generates in z-direction by tensile strain in z-direction. For this reason, the magnetization direction of the second magnetic layer **142** turns in x-direction, for example, because it is difficult for the magnetization of the second magnetic layer **142** to be in z-direction. In the case where the magnetization coefficient of the second magnetic layer **142** is negative, elastic energy generates in x-direction by compressive strain in z-direction. For this reason, the magnetization direction of the second magnetic layer **142** turns in z-direction, for example, because it is difficult for the magnetization direction of the second magnetic layer **142** to be in z-direction.

The magnetization direction of the first magnetic layer **141** and the second magnetic layer **142** can be in x-direction or in z-direction before the start of the step 2. For example, when the magnetization direction of the first magnetic layer **141** is in x-direction, the magnetization direction of the second magnetic layer **142** is easily controlled at the action of the step 2 because the magnetization direction of the second magnetic layer **142** can be in z-direction by applying the magnetic anisotropy derived from the fine line shape of the laminated structure **14**.

The magnetic domain wall can move from a first edge 'X1' of the first magnetic layer **141** to a second edge 'X2' of the first magnetic layer **141** by using the step 1 and the step 2 if the time duration (the time from t1 to t2) executing the step 1 is set longer than the time that the magnetic domain wall moves from the first edge X1 to the second edge 'X2'. The step 2 is started before the magnetic domain wall reaches the second edge 'X2'. The step 2 can be started before starting the step 1. Then, the step 2 is finished after finishing the step 1 (t2 t4).

FIG. **2** shows an example for timing which executes the step 1 and the step 2 in the case where the magnetic domain wall moves only through one first magnetic layer **141**. In FIG. **2** the step 1 is executed during executing the step 2 ($t3 \leq t1 \leq t2 \leq t4$). Thus, the magnetic domain wall can be stopped, before the second magnetic layer **142** if the step 2 is executed before starting the step 1 and after finishing the step 1. As shown in FIG. **2**C, the magnetic domain wall stops at the second edge 'X2' at the time executing the step 1 and the step 2 simultaneously because the magnetic domain wall can propagate in the first magnetic layer **141** and cannot propagate in the second magnetic layer **142**.

FIG. **3** shows an example for timing which executes the step 1 and the step 2 in the case where moving distance of the magnetic domain wall is longer than the case of the FIG. **2**. The moving distance can be controlled by changing the time from starting the step 1 to starting the step 2. In FIG. **3** the magnetic domain wall moves through two first magnetic layer **141** and one second magnetic layer **142**. For achieving this, the step 2 is executed, after the magnetic domain wall passes through the first of the first magnetic layer **141** and the first of the second magnetic layer **142** and reaches at the border 'X2' between the first of the second magnetic layer **142** and the second of the first magnetic layer **141** after starting the step 1 and before the magnetic domain wall reaches at the border 'X4' between the second of the first magnetic layer **141** and the second of the second magnetic layer **142**.

In FIG. **2** and FIG. **3** current and voltage are constant in the case of the step 1 and the step 2. However the current value passing between the first electrode **11** and the second electrode **12** can be changed in the case of the step 1, and the voltage value applying between the first electrode **11** and the third electrode **13** can be changed in the case of the step 2. For example, as shown in FIG. **4** the current value and the voltage value can be changed two steps. In the case where the current value being flowed in the step 1 is not temporally constant, for example, the transition time that the magnetic domain wall transits from the static state to the moving state can be shortened if the former current intensity except for rising edge is larger than the later current intensity. In the case where the given voltage value is temporally constant, for example, the magnetic anisotropy of the second magnetic layer **142** derived from the applied strain becomes larger if the later voltage is larger than the former voltage. Then, the magnetic domain wall can be stably stopped.

FIG. **5** shows an example that the step 1 and the step 2 are repeated respectively (in the case of the FIG. **5**, the repetition is three times). In the FIG. **5**, a schematic view showing the distribution of the magnetization of the magnetic layer after the step 1 and the step 2 are executed. In this example, each position of the magnetic domain wall moves on the distance corresponding to the length of the first magnetic layer **141** in laminating direction of the laminated structure **14** every time the step 1 and the step 2 are executed. Thus, the distance from the magnetic domain wall to the successive magnetic domain wall is unchanged even if the step 1 and the step 2 are executed repeatedly. This indicates that on the magnetic memory device **1** the data whose is reserved during the moving process of the magnetic domain wall is not lost even if the position of the magnetic domain wall is moved.

As explained above, executing the step flowing current between the first electrode **11** and a third electrode and the step flowing current between a first electrode and a second electrode enables to control the moving distance of the magnetic domain wall stably.

Materials of the magnetic layer **141**, **142** and the piezoelectric body **15** are explained. Several magnetic materials can be used for the first magnetic layer **141** and the second magnetic layer **142**. For example, at least iron (Fe), cobalt (Co), and nickel (Ni) are typical materials. An alloy related to these elements is also used for the typical materials. Furthermore, at least one of elements selected from manganese (Mn), chromium (Cr), and palladium (Pd) can be added to the alloy. As these materials are based, several magnetic characteristics are realized by adding nonmagnetic element to these materials. Permalloy (NiFe alloy) and CoFe alloy or like can be used as a material whose magnetic anisotropy is not so high.

Current can be smaller when the magnetic domain wall is moved by spin injection current if the magnetization direction is in perpendicular to the laminating direction of the laminated structure **14** (x direction in the FIG. **1**) rather than is in the laminating direction of the laminated structure **14** (z direction in the FIG. **1**). In order for the magnetization direction to be perpendicular to the laminated structure **14**, the magnetic anisotropy is needed to be large to overcome diamagnetic field because the diamagnetic field in the case where the magnetization direction is in orthogonal direction (short axis) to the laminated structure **14** is larger than the diamagnetic field in the case where the magnetization direction is in the direction of the laminated structure **14**. For this reason, it is notable to use material comprising large magnetic anisotropy.

Following materials can be used for the material comprising large uniaxial-magnetic anisotropy (Ku). At least one element selected from iron (Fe), cobalt (Co), nickel (Ni), manganese (Mn), and chromium (Cr) and at least one element selected from platinum (Pt), palladium (Pd), iridium (Ir), Ruthenium (Ru), and Rhodium (Rh) can be used for the large uniaxial-magnetic anisotropy material. The value of the uniaxial-magnetic anisotropy can be controlled by adjusting the composition of the magnetic layer or crystalline arrangement in annealing.

Magnetic material that comprises hexagonal closed packing structure and perpendicular magnetic anisotropy to the laminating direction of the laminated structure **14** can be also used for the large uniaxial-magnetic anisotropy material. Metal comprising cobalt (Co) can be used for these materials. The other metal comprising the hexagonal closed packing structure can also be used.

In the case where the laminating direction of the laminated structure **14** is formed perpendicular to the substrate, it is needed for the easy axis of the magnetic anisotropy is in plane in order for the magnetization direction is in perpendicular to the laminated structure **14**. Co, CoPt, and CoCrPt are used for material which comprises large magnetic anisotropy and that the easy axis of the magnetic anisotropy is in plane. CoPt and CoCrPt can be used as alloy. These materials are metallic crystalline whose c-axis of hexagonal closed packing structure is in plane. Furthermore, above any cases, additional elements can be added.

In the case where the laminating direction of the laminated structure **14** is formed parallel to the substrate (in the case where the laminated structure **14** is formed parallel in plane of substrate), it is needed for the easy axis of the magnetic anisotropy to be perpendicular to the plane. Co and CoPt, that c-axis of hexagonal closed packing structure is perpendicular to the plane, FePt, multilayer of (Co/Ni), and TbFe can be used for realizing these. CoPt can be used as alloy. In the case of using TbFe, TbFe comprises perpendicular magnetic anisotropy if Tb composition is ranged from 20 atomic % to 40 atomic %. Furthermore, above any cases, additional elements can be added.

The laminated structure **14** is formed perpendicular to the substrate better than the laminating direction of the laminated structure **14** is formed parallel to the substrate. This is because in this case the length of the second magnetic layer **142** in the fine line direction can be shorten and data amount in the laminated structure **14** can be larger.

The first magnetic layer **141** and the second magnetic layer **142** can be controlled by adding additive elements. The magnetostriction constant of the magnetic material added Ni element shifts to negative direction compared to the magnetic material without Ni element. The change amount of the magnetostriction constant of the magnetic material added Ni element depends on additive amount of Ni element. For example, by adding Ni element to the magnetic material comprising positive magnetostriction constant, the magnetostriction constant can be smaller. The magnetostriction constant can be almost zero by increasing additive amount of Ni element. Thus, positive or negative magnetostriction constant magnetic material can be used for the second magnetic layer **142**. Positive magnetostriction constant magnetic material, added Ni element in order for the magnetostriction constant to be almost zero, comprising same material as the first magnetic layer **141** or different from that of the first magnetic layer **141** can be used for the first magnetic layer **141**. These compositions can fabricate the magnetic memory device in this embodiment. The magnetic material can be negative magnetostriction constant by increasing content of Ni element. Thus, by adding Ni element to either the first magnetic layer **141** or the second magnetic layer **142**, and forming positive magnetostriction constant material to one of the first magnetic layer **141** and the second magnetic layer **142**, and negative magnetostriction constant material to the other can fabricate the magnetic memory device in this embodiment.

For another example, as method for shifting the magnetostriction constant to positive side, adding minute amounts of oxygen to the magnetic layer enables to control content of oxygen of the magnetic layer. Using this method enables to control small-negative magnetostriction constant for the material comprising large-negative magnetostriction constant and to form the material whose magnetostriction constant is almost zero. For example, the material whose magnetostriction constant is almost zero can be realized as the first magnetic layer **141**. Or, these materials can be also used for the first magnetic layer **141** and the second magnetic layer **142** in order to be positive magnetostriction constant.

Rare earth and iron group transition element related alloy comprising perpendicular magnetic anisotropy in the fine line direction can be used. As this alloy, GdFe, GdCo, GdFeCo, TbFe, TbCo, TbFeCo, GdTbFe, GdTbCo, DyFe, DyCo, or DyFeCo can be used for the first magnetic layer **141** and the second magnetic layer **142**.

Magnetic property, crystalline property, mechanical property, chemical property or various properties can be adjusted by adding nonmagnetic element such as Ag, Cu, Au, Al, Mg, Si, Bi, Ta, B, C, O, N, Pd, Pt, Zr, Ir, W, Mo, Nb, or H to these magnetic materials used for the magnetic layer can be controlled.

Piezoelectric body being single crystalline or uniaxial can be used for the piezoelectric body **15** in order to be uniform strain applied to the laminated structure **14**. Potassium sodium tartrate ($KNaC_4H_4O_6$), zinc oxide (ZnO), aluminum nitride(AlN), lead zirconium titanate ($PZT(Pb(Zr,Ti)O_3)$), zirconium titanate lanthanum lead (PLZT), crystal (SiO_2), lithium niobate ($LiNbO_3$), lithium tantalate ($LiTaO_3$), lithium tetraborate ($Li_2B_4O_7$), potassium niobate ($KNbO_3$), langasrte crystalline ($La_3Ga_5Si_{14}$ or like), or potassium sodium tartrate tetrahydrate ($KNaC_4H_4O_64H_2O$) or like can be used for the piezoelectric body **15**. On the basis of these piezoelectric materials, additive elements can be added in order to adjust property. The piezoelectric body **15** can be multilayer of these materials.

The materials same as used for the first magnetic layer **141** can be used for the ferromagnetic layer **162**, **172** in the writing section **16** and the reading section **17**.

Nonmagnetic metal or insulating film can be used for the nonmagnetic layer **161**, **171** of the writing section and the reading section **17**. One of the elements selected from Au, Cu, Cr, Zn, Ga, Nb, Mo, Ru, Pd, Ag, Hf, Ta, W, Pt, and Bi or alloy comprising at least one of these elements can be used for the nonmagnetic metal. The thickness of the nonmagnetic layer **161**, **171** is the length so that magnetostatic coupling between the ferromagnetic layer **162**, **172** and the magnetic layer **141** can be small and is smaller than spin diffusion length of the nonmagnetic layer **161**, **171**. The thickness of the nonmagnetic layer **161**, **171** is ranged from 0.2 nm to 20 nm.

It is effective for the nonmagnetic layer **161**, **171** to be used as tunneling barrier layer for insulating material used for the nonmagnetic layer **161**, **171** in order to gain large magnetoresistive effect. In this case, Al_2O_3, SiO_2, MgO, AlN, Bi_2O_3, MgF_2, CaF_2, $SrTiO_3$, $AlLaO_3$, Al—N—O, Si—N—O, nonmagnetic semiconductor (ZnO, InMn, GaN, GaAs, TiO_2, Zn, Te, or doped transition metal into these materials), or like can be used for the nonmagnetic layer **161**, **171**. These compounds are not completely correct composition stoichiometrically, and can be luck or excess of oxygen, nitrogen or, fluorine. The thickness of the nonmagnetic layer **161**, **171** comprised of this insulating material is raged from 2 nm to 5 nm. In the case where the nonmagnetic layer **161**, **171** is insulating layer, pinhole (PH) can be in the nonmagnetic layer **161**, **171**.

Fabrication process of the magnetic memory device will be explained. The magnetic memory device **1** is fabricated by used of sputtering and lithography. The fabrication process of the magnetic memory device **1** is explained as the following.

First, a silicon substrate is etched by use of a mask and the second electrode **12** is buried in the silicon substrate. Next, the first magnetic layer **141** is deposited on the silicon substrate where the second electrode **12** is buried. And, a nonmagnetic layer, a ferromagnetic layer, and a metal layer (can be used as electrode) are deposited on the first magnetic layer **141** in this order.

Next, the writing section **16** and the reading section **17** are formed by use of a mask and etching from the metal layer to the nonmagnetic layer so that the surface of the magnetic layer of the first magnetic layer **141** is uncovered.

Next, an insulating layer is deposited on the first magnetic layer **141** and the metal layer of the writing section **16** and the reading section **17**. Then, an opening is formed by etching the insulating layer so that the part of the insulating layer is uncovered.

Next, the laminated structure **14** whose height is over the height of the writing section **16** and the reading section **17** is formed by depositing the second magnetic layer **142** and the first magnetic layer **141** alternately. For example, the deposition repeat count is about 200 layers.

Furthermore, the first electrode **11** is formed on the first magnetic layer **141**, and the piezoelectric body **15** is formed on the first electrode **11**, and the third electrode **13** is formed on the piezoelectric body **15**. Finally, the surround of the magnetic memory device is buried by an insulating layer.

Modified Example

This embodiment can be used for any transformation. In the FIG. **1** and above explanation, voltage is applied between the first electrode **11** and the third electrode **13**. However, as shown in FIG. **6** the piezoelectric body **15** can be shrunk by applying voltage between the second electrode **12** and the third electrode **13**.

As shown in FIG. **7**, some bits data can be stored in one first magnetic layer **141** if the thickness of the first magnetic layer **141** is enough thick in the laminating direction (z direction).

Some concaves whose cross sectional area of the laminated structure **14** are different from the other part of the laminated structure **14** can be provided in the laminated structure **14** in the laminating direction (z direction), at regular interval. If such area is provided, pinning potential become higher for the magnetic domain wall and the magnetic domain wall is easy to be controlled.

As shown in FIG. **8**, anisotropy of the second magnetic layer **142** can be easily controlled by inverse-magnetostrictive effect because the second magnetic layer **142** is applied larger strain than the first magnetic layer **141** if the cross sectional area of the second magnetic layer **142** is smaller than the first magnetic layer **141**.

In the case where the cross sectional area of the second magnetic layer **142** is differentiated by the distance from the piezoelectric body **15**, the strain applying to the second magnetic layer **142** can be equalized if the thickness of the second magnetic layer **142** comprising small cross sectional area is larger than the thickness of the second magnetic layer **142** comprising large cross sectional area.

The laminated structure **14** can be surrounded by the piezoelectric body **15**. FIG. **9**A is a schematic view showing the cross sectional image of the magnetic memory device **5** being provided so that the laminated structure **14** is surrounded by the piezoelectric body **15** in the axis of the laminated structure **14**. FIG. **9**B is an upper view of the magnetic memory device **5**. By providing the piezoelectric body **15** like this, the laminated structure **14** can be applied strain uniformly when voltage is applied between the third electrode **13** and a fourth electrode **13***a*.

In FIG. **9** the piezoelectric body **15** is provided so that the piezoelectric body **15** is contact with the laminated structure **14**. However, as shown in FIG. **10** an insulator **20**, such as an amorphous SiO_2, an amorphous Al2O3, can be formed between the laminated structure **14** and the piezoelectric body **15**.

FIG. **11** is an example showing that the laminated structure **14** is formed in parallel to a substrate. The third electrode **13** and the fourth electrode **13***a* is provided upper side and lower side of the piezoelectric body **15**, and electric field can be applied to the upper and lower of the laminated structure **14**. In this case, the laminated structure **14** can be surrounded by the piezoelectric body **15** as shown in FIG. **12** showing a cross sectional image being cut on A-A line in the figure. Or, as shown in FIG. **13** and FIG. **14**, the piezoelectric body **15** can be provided on only the upper side and the lower side of the laminated structure **14**.

FIG. **15** is a schematic view of the magnetic memory device **7** so that the laminated structure **14** is surrounded by the piezoelectric body **15**. FIG. **15** is an example that shows the shape and position of the third electrode **13** and the fourth electrode **13***a* of the magnetic memory device **5**, shown in FIG. **9**, are changed. In this example, each of the third electrode **13** and the fourth electrode **13***a* comprises a pillar shape. Electric field is applied in the direction orthogonal to the laminating direction of the laminated structure **14** if voltage is applied between the third electrode **13** and the fourth electrode **13***a* by the step 2, because the laminated structure **14** is provided in the plane position connecting from the third electrode **13** to the fourth electrode **13***a*.

In this case, the operation is essentially the same as that in the case where electric field is applied in the laminating direction of the laminated structure **14** mentioned above. The magnetization direction of the second magnetic layer **142** is in the orthogonal direction to the laminated structure **14**, and in the case where the magnetostriction constant of the second magnetic layer **142** is positive, for example, the elastic energy increases in the orthogonal direction to the laminating direction of the laminated structure **14** and the magnetization direction cannot keep the orthogonal direction to the laminating direction of the laminated structure **14** and the magnetization direction results in being in parallel direction to the fine line, by applying voltage so that compressive strain is applied between the third electrode **13** and the fourth electrode **13***a* in the orthogonal direction to the laminating direction of the laminated structure **14**. Thus, in this case, the magnetic domain wall can also be stopped at the second magnetic layer **142** by use of the step 2. In this case, the third electrode **13** and fourth electrode **13***a* can comprise different cross sectional area respectively.

As shown in FIG. **16**, the third electrode **13** and the fourth electrode **13***a* can be as formed in flat plate shape, plural laminated structures **14** can be provided in a pair of the third electrode **13** and the fourth electrode **13***a*. In this case, the number of lines to select the third electrode **13** and the fourth electrode **13***a* can be diminished because the third electrode **13** and the fourth electrode **13***a* can be used commonly for the plural laminated structures **14**. The selectivity of the laminated structure **14** is not lost even if the third electrode **13** and the fourth electrode **13***a* is used commonly for the plural laminated structures **14**, because the magnetic domain wall motion does not generate even if the only step 2 is executed.

As shown in FIG. **17**, the first magnetic layer **141** and the second magnetic layer **142** can be provided on the both edges of the first magnetic layer **141**, and the writing section **16** and the reading section **17** are provided on the edges.

Second Embodiment

FIG. **18** is a schematic view of a cross sectional image of the magnetic memory device of the second embodiment. The same components as the magnetic memory device **10** of the first embodiment are shown by the same sign, and detail explanation is omitted. The magnetic memory device **10** of the second embodiment comprises the laminated structure **14***a* being arrayed the second magnetic layer **142** and a third magnetic layer **143** alternately in the place of plural second magnetic layer **142** of the magnetic memory device **1** of the first embodiment. The second magnetic layer **142** or the third magnetic layer **143** is provided between the first magnetic layers **141** of the laminated structure **14***a*, and the second magnetic layer **142** is provided between a first phase of the first magnetic layer **141** and the first magnetic layer **141** which is near to the first phase, and the third magnetic layer **143** is provided between the opposite phase to the first phase and the first magnetic layer **141** which is near to the opposite phase.

Each of the absolute value of the magnetostriction constant of the second magnetic layer **142** and the third magnetic layer **143** is larger than the absolute value of the magnetostriction constant of the first magnetic layer **141**, and the magnetostriction constant of the second magnetic layer **142** is opposite to that of the third magnetic layer **143**. Hereinafter, for example, the embodiment will be described that the sign of the magnetostriction constant is positive, and the sign of the third magnetostriction constant is negative.

The steps that magnetic domain wall in the laminated structure **14***a* of the magnetic memory device **10** is moved in the fine line direction at regular interval will be described. These steps comprise a step 1 that current is applied between the first electrode **11** and the second electrode **12** from the time t1 to the time t2 as shown in FIG. **19**A, a step 2 that positive voltage is applied between the first electrode **11** and the third electrode **13** from the time t3 to the time t4 as shown in FIG. **19**B, and a step 3 that negative voltage is applied between the first electrode **11** and the third electrode **13** from the time t5 to the time t6.

Current applied in the laminated structure **14***a* is spin-polarized, and spin torque is applied to the magnetization of the first magnetic layer **141**, the second magnetic layer **142**, and the third magnetic layer comprising the laminated structure **14***a* when current is applied between the first electrode **11** and the second electrode **12** by the step 1. Thus, the magnetic domain wall moves in the laminated structure **14***a*. The motion direction of the magnetic domain wall is the same direction as the motion direction of electron. Thus, the motion direction of the magnetic domain wall is opposite to the current direction.

Electric field is generated in the direction connecting the first electrode **11** to the third electrode **13** in a piezoelectric layer **15** when positive voltage is applied between the first electrode **11** and the third electrode **13** by the step 2. Then, in the case where the electric field direction is same as the direction of polarization of the piezoelectric body **15**, the piezoelectric layer **15** is extended in the direction connecting the first electrode **11** to the third electrode **13**. In the case where the electric field direction is opposite to the direction of polarization of the piezoelectric body **15**, the piezoelectric body **15** is compressed in the direction connecting the first electrode **11** to the third electrode **13**. The applied strain corresponding to this compression is applied to the laminated structure **14***a* through the first electrode **11**. In this case, magnetic anisotropy is induced by the applied strain due to the inverse-magnetosrtictive effect in the second magnetic layer **142** and the magnetization direction of the second magnetic layer **142** changes from the state before starting the step 2. Although the magnetic anisotropy is also induced by the applied strain due to the inverse-magnetostrictive effect in the third magnetic layer **143**, the magnetization direction of the third magnetic layer **143** does not change because the sign of the magnetostriction constant of the third magnetic layer **143** is opposite to that of the second magnetic layer **142**. As shown in FIG. **19**, in the case where the step 2 finishes before the completing time of the step 1 ($t4 \leq t2$), the magnetic domain wall does not pass through the second magnetic layer **142** at the time that the step 1 and the step 2 are executed simultaneously although the magnetic domain wall propagates in the first magnetic layer **141** and the third magnetic layer **143**. Thus, the second magnetic layer **142** works as stopping the magnetic domain wall motion during executing the step 2.

Electric field is generated in the piezoelectric layer **15** in the direction connecting the first electrode **11** to the third electrode **13** when negative voltage is applied between the first electrode **11** and the third electrode **13** by the step 3. Then, in the case where the electric field direction is same direction as the polarization direction of the piezoelectric body **15**, the piezoelectric body **15** extends in the direction connecting the first electrode **11** to the third electrode **13**. In the opposite case, the piezoelectric body **15** shrinks in the first electrode **11** to the third electrode **13**. The applied strain corresponding to this shrinking is applied to the laminated structure **14***a* through the first electrode **11**. In this case, the magnetic anisotropy derived from the applied strain generates by the inverse-magnetostrictive effect in the third magnetic layer **143** and the magnetization direction of the third magnetic layer **143** changes from the state before starting the step 3. Although the magnetic anisotropy derived from the applied strain also generates by the inverse-magnetostrictive effect in the third magnetic layer **143**, the magnetization direction of the third magnetic layer **143** does not change because the sign of the magnetostriction constant of the third magnetic layer **143** is opposite to that of the second magnetic layer **142**. As shown in FIG. **19**, in the case where the step 1 finishes before the completing time of the step 3 ($t2 \leq t6$), the magnetic domain wall does not pass through the third magnetic layer **143** at the time that the step 1 and the step 3 are executed simultaneously although the magnetic domain wall propagates in the first magnetic layer **141** and the second magnetic layer **142**. Thus, the third magnetic layer **143** works as a stopping layer where the magnetic domain wall stop moving during executing the step 3.

As mentioned above, by executing the step 1 and the step 3, for example, as shown in FIG. **19**C the magnetic domain wall can be moved from the first edge X1 of the first of the first magnetic layer **141** to the second edge X4 of next first magnetic layer **141**. As shown in FIG. **19**C, to move the magnetic domain wall from the first edge X1 of the first of the first magnetic layer **141** to the second edge X4 of the second of the first magnetic layer **141** sandwiching the second magnetic layer **142**, the start time and finish time of the step 1~step 3 are set as below.

Thus, after start of the step 1, the step 1 finishes after the time that the magnetic domain wall reaches the second edge X4 of the second of the first magnetic layer **141**. This enables the magnetic domain wall to reach stably the second edge X4 of the second of the first magnetic layer **141**. After start of the step 1, the step 2 starts before the time that the magnetic domain wall reaches the second edge X2 of the first of the first magnetic layer **141**. This prevents the magnetic domain wall from moving ahead of the second magnetic layer **142**. After start of the step 1, the step 2 finishes after the magnetic domain wall reaches the second edge X2 of the first of the first magnetic layer **141**, and after the step 2 finishes, the step 3 starts before the magnetic domain wall reaches the second edge X4 of the second of the first magnetic layer **141**. This enables the magnetic domain wall to move through the second magnetic layer **142**. And this enables also to prevent the magnetic domain wall from moving ahead of the third magnetic layer **143**.

As mentioned above, according to the magnetic memory device **10** of the second embodiment, when the magnetic domain wall moves through one of the second magnetic layer **142** and the third magnetic layer **143**, the magnetic domain motion can be controlled stably because the other prevents the magnetic domain wall from moving.

The step 2 and the step 3 can be executed plural times during executing the step 1. The number of the times of executing the step 2 and the step 3 can be determined corresponding to the number of first magnetic layer **141** that makes the magnetic domain wall moved. The finish time of the step 2 or the step 3 out of executing the step 2 or the step 3 plural times which is executed at final is to be after the finish time of the step 1. This enables the magnetic domain wall to move stably the distance corresponding to plural of the first magnetic layers **141** during given time.

The simulating result about the magnetic domain motion in the laminated structure comprising two second magnetic layers **142** and two third magnetic layers **143** is shown in FIG. **20**. The magnetization alignment shown in the top area in the FIG. **20**C is initial state. Current is applied between the first electrode **11** and the second electrode **12** (executing the step 1) on the basis of the timing chart shown in FIG. **20**A. Positive voltage and negative voltage are applied between the first electrode **11** and the third electrode **13** (executing the step 2 and the step 3) on the basis of the timing chart shown in FIG. **20**B. The simulating result in FIG. **20**C shows that the second magnetic layer prevents the magnetic domain wall motion during executing the step 1 and the step 2 simultaneously, and the third magnetic layer prevents the magnetic domain motion during executing the step 1 and the step 3 simultaneously.

Third Embodiment

A block comprising the magnetic memory devices being aligned, a writing section, and a reading section will be explained.

FIG. **22** is a schematic view of the block circuit of the third embodiment. FIG. **22** is a perspective view of the part of a block **50** of this embodiment. In the block of the third embodiment, a magnetic memory device R1 that the piezoelectric body is provided on the extending line connecting the first magnetic layer to the second magnetic layer is used for either of the magnetic memory devices explained in the first embodiment or the second embodiment and modified example related to the first embodiment or the second embodiment. The block of the third embodiment comprises the magnetic memory device R1, a switching device T (this device is comprised of a transistor, for example), and a memory track array MTA that is aligned like matrix state of m rows and n columns (m and n are positive integers). FIG. **2** shows the part of the memory track array MTA and the state that the memory track of 4 rows 4 columns is aligned.

A magnetic thin wire ML(i) (1≤i≤m) is comprised of each laminated structure, comprised of the n number of the magnetic memory devices R1 of the i th row (1≤i≤m), connected to the first magnetic layer being located at the edge of the laminated structure of neighboring magnetic memory device R1. the piezoelectric body **15** of the magnetic memory device R1 is provided between the magnetic thin wire ML(i) (i≤i≤m) and an electrode SL (for moving the magnetic domain wall) at every laminated structure. As mentioned above, in the case where the laminated structure of plural magnetic memory devices R1 is connected to the first magnetic layer, the electrode (the first electrode and the second electrode related to the first embodiment or the second embodiment and the modified example related to these embodiments) for applying current to the magnetic thin wire ML may not be provided at every magnetic memory device R1. Or the first electrode can be provided at one edge of the magnetic thin wire ML, the second electrode can be provided at the other edge of the magnetic thin wire ML. The magnetic thin wire may not be comprised of the magnetic memory devices R1 that each magnetic memory device R1 is connected each other. The first magnetic layer of each magnetic memory device R1 can be connected directly to peripheral circuit that will be mentioned.

The memory track array MTA comprises word lines WL(**1**) ~WL(m) which are provided on each row, the electrode SL(**1**) ~SL(m) like line shape, and bit lines BL(**1**)~BL(n) for reading information which are provide on each column. Plural word lines WL are aligned parallel each other, and the alignment of the electrode SL and the bit line is also same as the case of the word line WL. When viewing from z axis of FIG. **22**, the electrode SL extends in the direction parallel to the word line WL, and the bit line BL extends in the direction crossing the electrode SL and the word line WL.

A gate of the switching device T of each memory track is connected to the word line corresponding to each row, one edge of the gate is connected to one edge of the reading section **17** of the magnetic memory device R in the memory track, and the other edge of the gate is grounded. The other edge of the reading section **17** of the magnetic memory device R1 in the memory track is connected to the bit line BL corresponding to the memory track mentioned above.

As shown in FIG. **21**, the word lines WL(**1**)~WL(m), the magnetic thin wire ML(**1**)~ML(m), and the electrode SL(**1**) ~SL(n) are connected to a decoder selecting each line and drive circuit **410**A, **410**B comprising a writing circuit or like. The bit lines BL(**1**)~BL(n) are connected to a decoder selecting each line and drive circuit **420**A, **420**B comprising a reading circuit or like. In FIG. **21** and FIG. **22**, the writing section of the magnetic memory device R1 is omitted and not shown. One edge of the writing section can be connected to the switching device, not shown, for writing and selecting, and the other edge of the writing section can be a current source, not shown. The switching device for writing and the switching device for reading device can be used commonly for the writing selection. One reading section and one writing section can be provided for the plural memory tracks. In this case, this enables to make a high-density integration. In contrast, in the case where one reading section and one writing section are provided on each memory cell, the data transfer speed can be high.

The magnetic domain wall motion in the memory track of this embodiment will be explained. For example, as explained in the first embodiment, the magnetic memory device R1 comprises the laminated structure comprised of the first magnetic layer and the second magnetic layer. Address signal inputted from the external is decoded by the decoder in the drive circuit **410**A, **410**B, **420**A, **420**B, and the magnetic thin wire ML and the electrode SL corresponding to the address being decoded are selected, and the magnetic domain wall motion is executed (shift motion of data) by the step 1 applying current to this selected magnetic thin wire ML and the step 2 applying voltage to the electrode SL.

The step 1 and the step 2 are executed by using the timing explained in the first embodiment. In the case where the magnetic memory device R1 comprises the laminated structure comprised of the first magnetic layer, the second magnetic layer, and the third magnetic layer as explained in the third embodiment, the step 1, the step 2, and the step 3 are executed by using the timing explained in the second embodiment.

As mentioned above, by using this method of the magnetic domain wall motion in the memory track, the data position moves simultaneously in plural magnetic memory devices R1 included in the magnetic thin wire ML(i) comprising the magnetic thin wire ML(i) and existing on the same row of the memory track array MTA. Thus, data motion can be executed by one current source when plural magnetic memory devices are connected each other by sharing the first magnetic layer being provided on the edge of the magnetic memory device and the other first magnetic layer of the magnetic memory device. For this reason, electric power of the whole memory track array MTA can be reduced. The direction of the magnetic domain wall motion is same direction as the direction of electron current. Thus, the direction of the magnetic domain wall motion is opposite to the direction of electric current.

The writing to the memory track is executed when the decoder in the drive circuit **410**A, **410**B, **420**A, **420**B decodes the address signal inputted from the external part and the decoder chooses the word line WL corresponding to the address which is decoded and the switching device T is on. After that, data is written by applying current to the bit lie BL for reading information. Or data is written after moving the data reserved in the magnetic thin wire ML. For example, continuous data can be written fast when moving the distance corresponding to one bit and executing one bit data writing are executed alternately.

The data reserved in the memory track is read when the decoder in the drive circuit **410**A, **410**B, **420**A, **420**B decodes the address signal inputted from the external part and the decoder chooses the magnetic thin wire ML corresponding to the address being decoded and the data is shifted by use of above method so that the bit which is read is located on the reading section within bit column reserving the data in the memory track as the magnetization direction. After that, data is read when the decoder chooses the word line WL and sets the switching device T on and current is applied to the bit line BL for reading information. For example, continuous data can be read fast when moving the distance corresponding to one bit and executing one bit data reading are executed alternately. The direction of reading current can be positive or negative direction. The absolute value of the reading current is smaller than the absolute value of writing current. This enables the data reserved by the reading to prevent from inversion.

A memory tip can be formed when plural blocks **50** are used. FIG. **23** shows a schematic view of the memory tip that plural blocks **50** are used. The memory tip can be formed by putting plural blocks on a tip.

Modified Example

FIG. **24** is a schematic view of a block circuit of the first modified example of the third embodiment. FIG. **25** is a perspective view of a part of a block **51** of this modified example. In the case of the block **51**, the extending direction of a line shape electrode SL for moving the magnetic domain wall (also called electrode SL) is different from that of the block **50** shown in FIG. **22**. In the case of the block **50**, the electrode SL extends in the direction parallel to the word line WL viewing from z-direction in FIG. **22**. In the case of the block **51** of the first modified example the electrode SL extends in the direction (the direction crossing in the word line) parallel to the bit line BL for reading information viewing from z-direction in FIG. **25**. The detail composition other than the electrode SL is same as the block **50**, thus the detail explanation can be omitted.

The methods, the magnetic domain wall motion in the memory track of the block **51**, writing data to the memory track, and reading data reserved in the memory track are same as the case of the method of the block **50**.

FIG. **26** is a perspective view of a part of a block **52** of a second modified of the third embodiment. In the block **52**, the piezoelectric body **15** is shared with plural magnetic memory devices R1. As shown in FIG. **26**, the piezoelectric body **15** is provided on the upper part of the laminated structure of plural magnetic memory devices R1. Moreover, a plane shape electrode **15** is provided on the upper part of the piezoelectric body **15**. An insulator such as amorphous SiO_2, amorphous Al_2O_3 can be formed between the piezoelectric body **15** and the plane shape electrode **15**, or between the laminated structure of the magnetic memory device R1 and the piezoelectric body **15**. The detail composition other than the piezoelectric body **15** is same as the block **50**, thus the detail explanation can be omitted.

In FIG. **26** an example that plane shape piezoelectric body **15** is provided on the upper part of the laminated structure of plural magnetic memory devices R1 that are aligned to be matrix. However, the piezoelectric body **15** and the electrode SL can be provided at every column or every row of the memory track array MTA. The piezoelectric body **15** can be provided at every magnetic memory device R1 and the electrode can be provided on (or sandwiching the insulator) plural piezoelectric bodies **15**.

Applied strain can be added to plural laminated structures when voltage is applied to the piezoelectric body **15** by use of the electrode SL because in the case of the block **52** in FIG. **26** the piezoelectric body **15** is formed over the upper part of the laminated structure of plural magnetic memory devices R1. For example, the magnetic domain wall motion can be controlled every block when the piezoelectric body **15** is formed over the part of whole block **52**.

The word line WL, the bit line for reading information, the switching device T of the memory track, and the drive circuit **410**A, **410**B, **420**A, **420**B are an example. These position, shape, or composition can be changed arbitrarily.

Fourth Embodiment

FIG. **27** is a schematic view of a block circuit of the fourth embodiment. FIG. **28** is a perspective view of a part of a block of the fourth embodiment. The magnetic memory device R2 is used for a block **60** of the fourth embodiment that the piezoelectric body surrounds the peripheral of the laminated structure of the magnetic memory device of the first embodiment, the second embodiment, or the modified example. The piezoelectric body is provided on peripheral of the laminated structure of the magnetic memory device R2 comprising the magnetic thin wire ML (not shown in FIG. **28**). An insulator such as an amorphous SiO_2 or amorphous Al_2O_3 can be formed between the laminated structure of the magnetic memory device R2 and the piezoelectric body. This enables to keep insulation stably.

In the case where in FIG. **28** the magnetic thin wire ML is comprised of plural magnetic memory devices R2 being connected each other as mentioned in the third embodiment, the first electrode can be provided on one edge of the magnetic thin wire ML and the second electrode can be provided on the other edge of the magnetic thin wire ML for applying current to the magnetic thin wire ML. The first magnetic layer of each magnetic memory device R2 can be connected directly to peripheral circuit. The word line WL of the block **60**, the bit line for reading information, the switching device T of the memory track, and the drive circuit **410**A, **410**B, **420**A, **420**B are same as the block **50** of the third embodiment. Thus, the detail explanation is omitted.

In the block **60** shown in FIG. **28**, a plane shape electrode SL is provided between the magnetic thin wire ML and the other magnetic thin wire ML, and the plane shape electrode SL is aligned parallel to connecting direction of plural magnetic memory devices R2 of the magnetic thin wire ML. The shape of the electrode SL can be plane shape as shown in FIG. **28** or can be the other shape. In FIG. **28** the pair of electrode SL neighboring each other that sandwiching one magnetic thin wire ML(i). However, plural plane shape electrodes SL can be provided to sandwich whole magnetic thin wire ML(i) ($1 \le i \le m$).

For example, the plane shape electrode SL corresponds to the third electrode **13** in FIG. **15** and the fourth electrode **13***a* in FIG. **16**. This plane shape electrode SL is a pair of electrodes SL neighboring each other and sandwiching one magnetic thin wire ML(i) and has same function as one line shape electrode SL in FIG. **22**.

Plane shape electrode SL is connected to the drive circuit **410**A, **410**B via line. This enables to select the pair of electrode SL and apply electric field therein.

The magnetic domain wall motion in the memory track of this embodiment is same as the third embodiment. Thus, the decoder in the drive circuit **410**A, **410**B, **420**A, **420**B decodes the address signal inputted from the external part, and the decoder selects the magnetic thin wire ML and a pair of electrode SL corresponding to the address which is decoded, and a step 1 that current is applied to the magnetic thin wire ML which is selected and a step 2 that voltage is applied to the pair of electrode SL are executed. These steps enable the magnetic domain wall to move (data shift motion). The step 1 and the step 2 are executed at the timing explained in the first embodiment. In the case where the magnetic memory device R2 comprises the laminated structure of the first magnetic layer, the second magnetic layer, and the third magnetic layer as explained in the second embodiment, the step 1 and the step 2 are executed at the timing of the second embodiment.

Writing data to the memory track and reading data reserved in the memory track are same as the method of the third embodiment.

As mentioned above, data shift motion can be also executed by one current source in the fourth embodiment when the first magnetic layer being located on the edge of the magnetic memory device shares the other magnetic memory device and plural magnetic memory devices are connected. For this reason, power consumption of whole the memory track array MTA can be controlled. Thus, the direction of the magnetic domain wall motion is opposite to the direction of electric current.

Large capacity memory tip can be fabricated as explained in the third embodiment by using plural blocks in the fourth embodiment.

Modified Example

FIG. **29** is a schematic view of a block circuit of the first modified example of the fourth embodiment. FIG. **30** is a perspective view of a part of a block **61** of the modified example. In the fourth embodiment, the extending direction of plane shape electrode SL can be also changed same as the first modified example of the third embodiment. In the block **61** of the first modified example shown in FIG. **30**, the electrode SL extends in the direction parallel to the bit line BL for reading information (the direction crossing in the word line WL). A pair of electrodes SL is provided in the block **61** every laminated structure that the first magnetic layer, the second magnetic layer, and the third magnetic layer are laminated in z-direction of the magnetic memory device R2.

In FIG. **30**, electrode SL for one laminated structure is only shown. However, plural electrodes SL can be provided to sandwich each laminated structure. The composition other than the electrode SL is same as the case of the block **60**, thus the detail explanation is omitted.

The magnetic domain wall motion in the memory track of the block **61**, writing data to the memory track, and reading data reserved in the memory track are same as the case of the block **60**.

FIG. **31** is a perspective view of a block **62** of a second modified example of the fourth embodiment. In the block **62** of the second modified example of the fourth embodiment, the pair of electrodes SL is provided to sandwich the laminated structure of whole memory track included in the block.

In the case of the block **62** shown in FIG. **31**, when a voltage is applied to the piezoelectric body **15** being sandwiched by a pair of electrodes SL, a strain can be applied to the laminated structure being surrounded by the piezoelectric body **15** and the magnetic domain wall motion can be controlled every block.

The pair of plane shape electrodes SL can be provided every plural column of the magnetic thin wire ML(i). In this case, the number of the electrodes SL shown in FIG. **21** is smaller than the m number of the electrodes SL. This structure enables to decrease the area ratio of the electrode SL occupied in whole memory track. Thus, this structure has advantage for high integration. On the other hand, for example, as shown in FIG. **28**, in the case where the pair of electrodes SL is provided to sandwich one magnetic thin wire SL, selecting the magnetic thin wire executing the step 1 and the step 2 simultaneously becomes easier when the magnetic domain wall position is moved.

In the second modified example of the fourth embodiment, an example that the electrode SL is aligned parallel to the connecting direction of plural magnetic memory device R2 in the magnetic thin wire. However, the first modified example and the second modified example can be combined. The electrode SL can be aligned in direction orthogonal to connecting direction of plural magnetic memory devices R2 in the magnetic thin wire ML. This enables a pair of plane shape electrode SL to be provided every plural rows of the magnetic thin wire ML(i). The position that the electrode SL is provided toward the piezoelectric body **15** can be changed arbitrarily if electric field can be applied to the piezoelectric body **15**.

The word line WL, the bit line for reading information, the switching device T of the memory track, and the drive circuit **410**A, **410**B, **420**A, **420**B shown in this embodiment and the modified example related to this embodiment are an example. These position, shape, or composition can be changed arbitrarily.

The embodiments related to this invention are explained by using concrete examples. However, this invention is not limited to these embodiments. For example, concrete size of each element comprising the magnetic memory device, materials, electrodes, passivation, shape or composition related to insulating structure can be included in this invention if ordinary skill person execute this invention same as this embodiments by selecting ordinary skill arbitrarily and can gain same effect from doing that. For example, for each magnetic layer comprising a magnetic element, the shape and the size are not needed to be same, so the shape and the size can be fabricated as different each other. Each element of antiferromagnetic layer, intermediate layer, and insulating layer or like comprising the magnetic memory device can be formed as single layer or can be multiple layers that plural layers are laminated. The modified example explained in each embodiment can be applied to other embodiments or plural modified examples can be combined each other.

In basis of the magnetic memory devices or the magnetic recording device mentioned above as the embodiment of this invention, whole magnetic memory device or recording device that ordinary skill person can fabricate and change and execute arbitrarily can be included in this invention if the ordinary skill person executes within the aim of this invention.

The word "perpendicular" includes gap generated from a perpendicular that is derived from the variation of fabricating process. In the same way, the meaning of "parallel", "flat" are different from the meaning of absolute parallel or absolute flat.

While certain the embodiment of the invention has been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the embodiment of the inventions. Indeed, the novel elements and apparatuses described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein may be made without departing from the spirit of the embodiment of the invention. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the embodiment of the invention.

What is claimed is:

1. A magnetic memory device comprising:

a first electrode;

a second electrode;

a laminated structure comprising plural first magnetic layers being provided between the first electrode and the second electrode, a second magnetic layer comprising different composition elements from those of the first magnetic layer and being provided between plural first magnetic layers;

a piezoelectric body provided to surround the laminated structure in a laminated direction of the laminated structure; and

a third electrode and a fourth electrode applying a voltage to the piezoelectric body.

2. The device of claim **1**, a sign of a magnetostriction constant of the first magnetic layer is different from a sign of a magnetostriction constant of the second magnetic layer, or an absolute value of the magnetostriction constant of the first magnetic layer is smaller than an absolute value of the magnetostriction constant of the second magnetic layer.

3. The device of claim **1**, the laminated structure further comprising a third magnetic layer comprising a different sign of magnetostriction constant from a sign of magnetostriction constant of the second magnetic layer, the second magnetic layer and the third magnetic layer being provided alternately between the plural first magnetic layers.

4. The device of claim **1**, a magnetization direction of the second magnetic layer is changed when voltage is applied between the third electrode and the fourth electrode.

5. The device of claim **1**, the laminated structure further comprising a third magnetic layer comprising a different sign of magnetostriction constant from a sign of magnetostriction constant of the second magnetic layer, the second magnetic layer and the third magnetic layer being provided alternately between the plural first magnetic layers, and a magnetization direction of the second magnetic layer is changed when a first voltage is applied between the third electrode and the fourth electrode, and a magnetization direction of the third magnetic layer is changed when a second voltage whose sign is different from the first voltage is applied between the first electrode and the third electrode.

6. The device of claim **1**, further comprising a writing section making magnetization direction of the first magnetic layer begin changed when current is applied to the first magnetic layer and being provided on the first magnetic layer, and a reading section detecting resistance changes of the first magnetic layer and begin provided on the first magnetic layer.

7. The device of claim **1**, a cross sectional area of the first magnetic layer in a laminated direction of the first magnetic layer and the second magnetic layer is larger than a cross sectional area of the second magnetic layer in the laminated direction.

8. The device of claim **1**, the piezoelectric body comprising potassium sodium tartrate, zinc oxide, aluminum nitride, lead zirconium titanate, zirconium titanate lanthanum lead, crystal, lithium niobate, lithium tantalate, lithium tetraborate, potassium niobate, langasrte crystalline, or potassium sodium tartrate tetrahydrate.

9. The device of claim **1**, the laminated structure being laminated in perpendicular direction to a substrate, the first magnetic layer and the second magnetic layer comprising GdFe, GdCo, GdFeCo, TbFe, TbCo, TbFeCo, GdTbFe, GdTbCo, DyFe, DyCo, or DyFeCo.

10. The device of claim **1**, the laminated structure being laminated in parallel direction to a substrate, the first magnetic layer and the second magnetic layer being comprised of multilayer of (Co/Ni) or comprising GdFe, GdCo, GdFeCo, TbFe, TbCo, TbFeCo, GdTbFe, GdTbCo, DyFe, DyCo, or DyFeCo.

11. A method of magnetic domain wall motion of the device of claim **1**, comprising a first step applying a current between the first electrode and the second electrode for a first time duration, a second step applying a voltage to the piezoelectric body for a second time duration, wherein a completing time of the second step is after a completing time of the first step.

* * * * *